ICES PLADS I

THE PLASTIC ANALYSIS AND DESIGN SYSTEM

FOR

FRAMED STRUCTURES

A THESIS

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SUMMARY

A computerized design system written in FORTRAN for the plastic analysis and design of multistory steel frames exists (5,6,7). The purpose of this thesis is to report on extensions to this analysis and design system. These extensions are described as follows.

1. Incorporate into the system automatic consideration of live load reduction coefficients.

2. Improve the convergence characteristics of the elastic stiffness design when gravity sway deflections are critical.

3. Include consideration of column elongation in the calculation of delta in the P-delta effect.

4. Improve the method of computing approximate lateral displacements by incorporating a solution based on solving a tri-diagonal system of equations.

5. Develop a new subsystem of ICES, PLADS I, which incorporates the existing computer programs with the proposed extensions. This development requires the incorporation of ICETRAN (ICES FORTRAN) programming concepts into the existing programs as well as the development of a Problem Oriented Language (POL) to be used by the engineer to both specify his input as well as direct the design and analysis procedures.

A number of example problems are presented which illustrate that ICES PLADS I is both an efficient and practical design tool for both engineering office and academic use.

CHAPTER I

INTRODUCTION

The ever-increasing amount of research in the area of applications of plastic behavior of steel to the design of braced and unbraced multistory steel frames is leading to the development of plastic design methods which produce safe, functional and economical designs of multistory steel frames.

In 1958 plastic design methods were recommended for use in the design of one- and two-story buildings by the American Institute of Steel Construction (2). Acceptance of plastic design methods continued to grow with the publication of several manuals, handbooks and design aids which present accepted guidelines for the plastic design of braced multistory steel frames (1,2,3,12). <u>The Structural Engineering Handbook</u> (9) describes some provisions for plastic design in unbraced multistory steel frames. Due to continuing efforts in this area, the 1970 AISC Specifications (2) have included broad provisions for the plastic design of both braced and unbraced multistory steel frames.

Plastic analysis and design methods for multistory steel frames require the manipulation of enormous amounts of information which makes the use of the electronic digital computer extremely attractive, especially in the design of large structural systems. The development of more powerful computer hardware and software capabilities has virtually freed the structural engineer from the laborious hand computations allowing him to pay more attention to the creative aspects of the design process.

As reported in a research report and other publications by Leroy Z. Emkin and William A. Litle (6,7), a major computer based optimization system for the plastic analysis and design of braced and unbraced multistory rectangular steel frames has been developed. This existing FORTRAN computer system consists of five parts: (1) input of the design problem; (2) a strength design of factored ultimate loads; (3) an elastic analysis of working loads with the modification of member sizes when elastic stress limits are exceeded; (4) an elastic stiffness design if, at working loads, lateral story deflection limits are exceeded; and (5) output of design results.

The practicality of this existing system is apparent from the scope of its capabilities which are: (1) a consideration of both braced and unbraced multistory steel frames; (2) automatic member selection from user provided section tables; (3) a consideration of beam and column depth constraints throughout the design; (4) automatic determination of the location of bracing elements at the user's option; (5) automatic distribution of total required story shear and moment capacity into a story using an optimization algorithm to minimize steel weight; (6) automatic cycling of design to account for the P-delta effect; (7) automatic design to satisfy user imposed elastic stress constraints, and (8) automatic redesign to satisfy user imposed elastic lateral deflection constraints using an optimization algorithm to minimize steel weight.

The object of this Thesis is to improve and extend the capabilities of this existing computerized plastic analysis and design system. In order to extend its present capabilities, certain basic FORTRAN programming improvements are made to the existing computerized system. In conjunction with a review of the general methodology, philosophy, and construction of the existing computerized plastic design system, these FORTRAN programming improvements are described in detail in CHAPTER II and are briefly summarized as follows:

1. The routines of the existing system which control the input of the design problem data are revised to include automatic consideration of live load reduction and automatic refinements of working loading condition data to render this data conformable to the requirements of the system.

2. The existing plastic design part is revised to include the effects of column elongation and shortening in the calculation of delta for the P-delta effect.

3. The existing plastic design part is also revised

to include consideration of a strong column - weak beam design constraint. This constraint allows column design alterations to insure against the occurance whereby the columns in a particular story may reach their ultimate load capacity before the beams in the same story.

4. The existing elastic stiffness design part is revised to overcome a problem with convergence to a satisfactory design when gravity sway deflections control the design process. A method is included to eliminate the generation of an unsymmetrical stiffness configuration for the frame, which seems to be at the root of this problem.

5. The existing elastic stiffness design part includes an approximate method for computing relative story deflections due to beam and column bending, and brace elongation. This method is revised so the computation of relative story deflections due to story racking is based on the exact solution to a tri-diagonal, linear system of equations.

6. Several programming changes so that the plastic design algorithms maintain consistency with the 1970 AISC Manual of Steel Construction (2).

The major effort of the Thesis research, the results of which are reported in CHAPTER III and CHAPTER IV, was directed toward the development of a new computerized system, including the proposed FORTRAN programming extensions, as PLADS I (The Plastic Analysis and Design System), a subsystem of ICES (15). This development requires the incorporation of ICETRAN (ICES FORTRAN) programming concepts into the existing computer programs as well as development of a POL (Problem Oriented Language).

The ICES PLADS I subsystem consists of six separate parts: (1) complete system design part which will operate essentially as the existing plastic analysis and design computer system including the proposed programming changes; (2) a plastic analysis and design part; (3) an elastic stress and stiffness design part; (4) a stiffness analysis part; (5) a part to control design problem input, and (6) a part to control the generation of output of design results. The algorithms composing the design and analysis parts will remain, for the most part, unchanged from those employed by the existing computer system; however, these algorithms are regrouped employing the ICETRAN programming techniques and the POL to result in a new plastic analysis and design system, ICES PLADS I, with a completely new user-oriented philosophy. The ICETRAN programming concepts will provide the proposed ICES subsystem with increased data handling capability and efficiency, while the POL will allow the engineer user to control the input and output, and interact with the design and analysis processes. CHAPTER III also includes an introduction to the ICES Basic subsystem whose concepts are used in the development of ICES PLADS I, illustrating the practicality, applicability, and effectiveness of ICES PLADS I.

The research reported herein was conducted in part on the UNIVAC 1108 computer at the Office of Computer Services of the Georgia Institute of Technology and on the IBM 360/65 computer on the campus of the University of Georgia.

CHAPTER II

A REVIEW OF THE EXISTING FORTRAN COMPUTER DESIGN SYSTEM AND PROGRAMMING CHANGES

Introduction

The existing computerized plastic analysis and design system described in detail in References 5, 6, and 7 is reviewed in this chapter and consists of five basic parts which are:

1. Design problem input.
2. A strength design for factored ultimate gravity and lateral loads based on a story-by-story optimization procedure in order to determine the most favorable force distribution for the frame in order to minimize material cost. This strength design accounts for the P-delta effect due to gravity loads acting on the frame in a laterally displaced position.
3. An elastic analysis for working loads with modification of member sizes when elastic stress limits are exceeded. This part performs an exact matrix stiffness analysis of the structure and redesigns members in order to satisfy user-imposed elastic stress constraints.
4. An elastic stiffness design for service

loads executed in order to satisfy user-imposed elastic lateral deflection constraints. This part also employs an optimization technique in order to minimize the material cost increase needed to satisfy the lateral deflection constraints.

5. Output of design results.

In order to improve the efficiency of the existing plastic analysis and design system and extend its present capabilities, several basic programming changes are made and described as follows:

1. In order to properly consider live load reduction effect on column design in the existing system, extensive hand modification to the working load data was necessary prior to the input of this data.

This requirement is extremely unattractive from a user point of view. Consequently, the automatic refinement of working load data and automatic consideration of live load reduction on column design is incorporated into the existing design system.

2. The method of calculating the relative story deflections of the failure mechanism used by the existing plastic analysis and design system considers only lateral deflections due to beam and column bending and brace elongation, and neglects the effects of column elongation and shortening which could be significant at the ultimate load failure mechanism. To correct this

inaccuracy, the calculation of delta for the P-delta effect is improved by including consideration of effects due to column elongation and shortening.

3. In the elastic stiffness design part, a problem occurs with the convergence to a satisfactory design when gravity sway deflections become significant. This problem occurs when, during the execution of the elastic stiffness design method, an unsymmetrical stiffness configuration is generated for the frame under design. This problem is overcome by including into the existing elastic stiffness design process a feature which allows the modification of member properties to occur, during the design of a given story, alternately between the members in the left and right halves of the frame which is divided according to the number of bays.

4. It is currently accepted practice in plastic design to provide assurance that plastic hinges form in beams before they form in columns. The existing plastic analysis and design system does not consider this; therefore, a method is incorporated into the existing plastic design part to perform a design check according to the strong column - weak beam design constraint which will be satisfied if the sum of the reduced plastic moment capacities of the columns framing into a given joint exceeds the sum of the reduced plastic moment capacities of the beams framing into that given joint, where the

reduced plastic moment capacity of a member is the maximum allowable moment in the presence of axial force.

5. In the existing elastic stiffness design part, the method for computing approximate relative story deflections due to beam and column bending and brace elongation is an approximate solution to a tri-diagonal system of simultaneous equations based on successive substitutions. To improve the efficiency of this computation, it is revised to perform an exact solution to this set of simultaneous equations.

In addition to the implementation of the five major FORTRAN programming extensions listed above, several programming changes were made to the plastic design part in order that the design processes employed by this part remain consistent with current guidelines established by the 1970 edition of the AISC Manual of Steel Construction (2).

Review of the Existing Plastic Analysis and Design System

The following is a review of the existing computerized plastic analysis and design system.

Input of the Design Problem

The existing design system considers rectangular multistory braced or unbraced plane frames. The maximum allowable number of bays is five and the maximum allowable number of stories is 30.

The loading conditions for any frame under design are input as dead plus live load (DL+LL) and dead plus live plus wind load (DL+LL+WL). The DL+LL condition consists of a uniformly distributed linear load per foot applied to the girders and concentrated vertical loads applied at the joints. Wind loads are concentrated horizontal loads applied to the external joints of the frame. Ultimate loads applied to the frame are calculated by multiplying the working loads by appropriate load factores which are also input into the system.

Material properties are input as the grade of steel specified by its yield stress. This data must be input for each and every member including bracing even though bracing may not be used in every bay.

The other material property which also must be input is the unit material cost associated with the yield stress of each member.

Certain constraints must be input in order to direct the design and analysis of the existing system. These constraints are listed as follows:

1. Maximum permissible elastic member stresses under working loads.

2. Maximum permissible relative story deflections under working loads.

3. Maximum permissible beam and column depths.

4. Actual maximum unsupported beam and column lengths with respect to out of plane deformations.

5. Panel codes indicating allowable modes of panel shear resistance.

Assumed initial story deflections at the collapse mechanism are input to be used in an iterative procedure which accounts for P-delta effects during the plastic design part.

The steel sections to be used in the design process may consist of appropriate series of rolled sections for beams, columns and braces. The sections and their properties are input in tabular form. The beam section table consists of two parts. The first part, which is required, consists of economy beam sections ordered on increasing cross-sectional area without regard to depth constraints. The second part, which is optional, consists of non-economy beam sections ordered on increasing plastic section modulus to be used when beam depth constraints are critical.

The column section table also consists of two parts. The first part, which is required, consists of commonly used column sections ordered on increasing section area without regard to depth constaints. The second part, which is optional, consists of columns ordered on increasing area to be used when column depth constraints are critical.

The brace section table is a one-part table consisting of a series of available brace sections ordered on increasing cross-sectional area.

There is also a side constraint not input, but automatically assumed by the existing plastic analysis and design system. It is that the same column section be used in two successive stories in any column line.

The Plastic Design Part

The existing plastic design part begins with the determination of the minimum section property configuration from the force distribution resulting from the assumption of beam mechanism failures for each beam under factored gravity loads. Using this force distribution and the appropriate design formulas, all the beams and columns are designed and selected from the beam tables and column tables respectively.

The design continues with a consideration of the factored combination wind plus gravity load condition. The total required story shear capacity for each story is determined as the sum of the factored wind loads plus the P-delta shear which is an expression of the additional story overturning moment due to the factored gravity loads acting in the laterally displaced position of the frame at ultimate loads.

This design procedure starts at the top story and proceeds in a step-by-step manner to the bottom story. At each story level the total required story shear is distributed into the panels of the story in an incremental fashion using a procedure based on a distribution coefficient called a sensitivity coefficient. The sensitivity coefficient is defined as the increase in cost of a panel due to an increase in lateral shear capacity of a panel. Incremental panel shear capacity may be provided by moment resistance or truss resistance (with a tension brace). Each type of capacity for each panel in a story is represented by a sensitivity coefficient and and panel with the smallest coefficient receives the next increment of lateral story shear.

After each increment of lateral shear is distributed into a given story, a new member force distribution is determined and members are appropriately redesigned. This process continues until a satisfactory design is reached.

Elastic Analysis and Stress Design Part

Following the existing plastic analysis and design method, the elastic analysis and elastic stress design method is automatically executed.

An exact matrix elastic stiffness analysis is performed on the frame previously designed in the plastic design part, but subjected to working loads. This analysis provides maximum elastic member stresses which are compared to the specified maximum permissible elastic member stresses. If maximum permissible elastic stresses were not specified previously, the member yield stress is assumed as the maximum permissible member stress not to be exceeded under working loads. Those members whose working stress exceeds their maximum allowable elastic member stress are redesigned. This elastic analysis and design method proceeds until all of the member working stresses are less than or equal to their maximum allowable elastic stresses.

The Elastic Stiffness Design Method

The elastic stiffness design method is executed if one or more of the relative story deflections calculated by the exact matrix stiffness method violate the specified deflection constraints. During the elastic stiffness design, an optimization procedure is used to modify the member properties. In addition, approximate relative story deflections are calculated.

The approximate deflection calculation assumes that the approximate relative story deflections are composed of the superposition of three types of deflections due to wind load alone and a fourth type due to gravity load. The first three types of deflection are due respectively to beam and column bending and brace elongation, column elongation and shortening and beam elongation and shortening. The fourth type of deflection is due to gravity sway deflections resulting from unsymmetrically distributed gravity loads or from gravity loads acting on a structure with an unsymmetrical stiffness distribution. During the elastic stiffness design optimization procedure, the approximate deflections are reduced until the deflection constraints are satisfied. The optimization procedure used is the same in principle as that used in the existing plastic design method. In particular, a deflection sensitivity coefficient is calculated for each member of the story under consideration. This deflection sensitivity coefficient is defined as the increase in cost of the member with respect to the member's effect on decreasing the relative story deflection under consideration. The member with least sensitivity coefficient is selected to increase in size by one section in the appropriate section table. This design process is repeated until each of the relative story deflection constraints initially violated are satisfied. After all stories satisfy the deflection constraints according to approximate deflection values, a new exact stiffness analysis is executed and new relative story deflections are determined. If these relative story deflections satisfy the imposed deflection constraints, the elastic stiffness design is terminated. Otherwise new approximate relative story deflections are calculated and the design optimization procedure is repeated for all the stories whose deflection constraints are violated. The above iterative design proceeds until all of the exact relative story deflections are finally satisfied.

Output of Results

Results are output not only for the final design, but for several intermediate stages. A description of the output from the various design stages follows.

1. Plastic design output.

Output from the plastic design part includes required member sizes for both the factored gravity load condition and the factored combination load condition, the force distributions under the two loading conditions (for both wind from the left and wind from the right for the combination loading condition), the panel shear capacity distributions, and the final total weight and material cost for the frame.

2. Elastic stress design output.

Output from the elastic stress design part includes the joint displacements from the stiffness analysis, internal member forces, elastic member stresses, member sizes before and after the elastic stress design, and the final total material weight and cost.

3. Elastic stiffness design output.

Output from the elastic stiffness design part includes the final relative story deflections calculated by the approximate deflection analysis, the member sizes before and after the elastic stiffness design and the final total material weight and cost.

General Design Limitations and Conditions

The design method summarized above considers braced rectangular multistory steel plane frames. When braced frames are considered, only diagonal pinned-end bracing elements in a given panel are considered. All members are prismatic and beams and columns are rigidly connected at the joints of the frames. Furthermore, all bottom story columns are assumed to be completely fixed to the foundation.

It is assumed that the geometrical and topological conditions of the frame, such as the number of stories and bays, the story heights and bay lengths, are determined from functional considerations for the frame; therefore, those geometrical conditions are considered fixed and are input into the design system.

There are two loading configurations considered in the existing plastic analysis and design system. The first loading condition is the combination of factored dead plus live loads composed of uniformly distributed gravity loads applied to the girders of the frame and concentrated gravity loads applied vertically to the joints of the frame. The second loading condition is the combination of factored dead plus live plus lateral loads where the lateral loads are applied as concentrated horizontal loads to the external joints from either side of the frame. All loads are taken as static loads.

Two additional important and extremely practical design constraints are considered in the existing design system. The first constraint is a maximum depth constraint for beams and columns. The user may specify a maximum beam and column depth which may not be exceeded in the design process. Allowing for this constraint is necessary due to functional requirements stemming from architectural, mechanical, electrical and other such considerations. The second constraint is the two story column constraint. Allowing for a consideration of the economics of the frame construction, the design process designs columns in two-story lengths.

Finally, the following basic assumptions are made in the existing plastic analysis and design method.

1. The stress-strain curve of steel is represented as an ideal elastic-plastic bilinear line where strain hardening effects are neglected.

2. The spread of yielding in a member is not considered. Instead, the concept of plastic hinge formation is adopted.

3. The frame and loadings are coplanar; consequently, biaxial bending moments are not considered.

4. For plastic design under gravity loads only, all diagonal bracing is neglected and the resulting unbraced frame alone is considered to provide the strength for the frame.

5. Under the application of the gravity plus wind loading condition, only diagonal tension bracing and beams and columns are assumed to contribute to the strength

and stiffness of the frame. Diagonal compression bracing is assumed to take on a buckled configuration under the application of gravity and lateral loads.

This concludes the brief summary of the philosophy and operation of the existing plastic analysis and design system.

Improvements Made to the Original Plastic Design Computer System

Improved Manipulation of Loading Condition Data

The loading conditions which must be input into the existing computerized plastic design system and also the proposed ICES subsystem, PLADS I, are the gravity loading condition and the gravity plus lateral loading condition, both of which were previously described under the second subheading of this chapter.

These loading conditions cannot be input into the system without extensive refinement by the engineer user in order to account for live load reduction in column design. Therefore, a programming change is made to the existing system to include automatic consideration of live load reduction effects on column design.

The gravity and the gravity plus lateral loading conditions are composed of vertical concentrated loads applied to each joint, uniformly distributed loads applied to each girder, and horizontal concentrated loads applied to each external joint of the frame under design. These are working loads.

The girder loads are formulated from dead and reduced live loads applied uniformly over a full bay converted to linear loads per foot applied to the girder. For input to the existing plastic analysis and design system, the engineer user must compute for each girder the uniformly distributed girder load as the product of the floor load and the bent spacing. The dead and live load must be computed separately because for large floor areas, the live load may be reduced due to the high probability that the maximum live floor load may not act over the entire floor area simultaneously. Note that for the existing design system and the proposed ICES PLADS I subsystem, the probability that the maximum live load does not act over the entire floor area does not allow the user to design for checkerboard loading conditions. The computed dead and live girder loads are then combined to form the gravity working loads for girders which are input into the system.

In the existing computerized plastic analysis and design system, the user is also required to input concentrated vertical joint loads which are generated by extensive hand manipulation of dead and live working uniform girder loads and concentrated joint working loads. These extensive hand computations are necessary so that, ultimately, the factored column gravity axial loads com-computed by the existing system reflect live load reduction. In the existing computerized system, these vertical concentrated joint loads are calculated according to the following procedure:

1. The live load reduction coefficients are specified for the beams and columns.

2. The girder gravity loads, which are input into the existing system, are computed to reflect the reduction of live girder loads by the following expression:

$$PW(i,j) = BEAMDL(i,j) + (1.0 - RCB(i,j))BEAMLL(i,j) \quad (1)$$

where,

PW(i,j) = the uniformly distributed girder gravity load applied to the jth girder in the ith story.

BEAMDL(i,j) = the uniformly distributed girder dead load applied to the jth girder in the ith story.

BEAMLL(i,j) = the uniformly distributed girder live load applied to the jth girder in the ith story.

RCB(i,j) = the live load reduction coefficient for the jth girder in the ith story.

3. The total column live and dead loads are computed for every column in every story using the following expressions:

$$TOTCDL(k,j) = \sum_{i=1}^{k} (JOINTDL(i,j) + (BEAMDL(i,j) \quad (2)$$

$$RL(j) + BEAMDL(i,j-1)RL(j-1))/2.0)$$

where,

TOTCDL(k,j) = the total column dead load carried in the jth column of the kth story.

JOINTDL(i,j) = the specified concentrated vertical joint dead load applied to the jth joint in the ith story. These loads may arise from the transfer of floor loads to this joint via spandrel beams framing the bent under consideration to adjacent bents, where

RL(j) = the length of the jth panel

$$\text{TOTCLL(k,j)} = \sum_{i=1}^{k} \text{(JOINTLL(i,j) + BEAMLL(i,j)RL(j)} \quad (3)$$

$$\text{+ BEAMLL(i,j-1)RL(j-1))/2.0)}$$

where,

TOTCLL(k,j) = the total column live load carried in the jth column of the kth story.

JOINTLL(i,j) = the specified concentrated vertical joint live load applied to the jth joint in the ith story. As for JOINTDL(i,j), these loads may arise from the transfer of floor loads to this joint via spandrel beams framing the bent under consideration to adjacent bents.

4. The reduced column live loads are computed according to the following expressions:

$$\text{REDCLL(i,j) = (TOTCLL(i,j) - NORED(i,j))(1.0 -} \quad (4)$$

$$\text{RCC(i,j)) + NORED(i,j)}$$

where,

REDCLL(i,j) = the reduced column live load in the jth column of the ith story.

NORED(i,j) = the sum of all TOTCLL(i,j)'s associated with column live load coefficient values of 0.00. In many cases this will include only TOTCLL(1,1).

RCC(i,j) = the live load reduction coefficient associated with the jth column in the ith story.

5. Finally, concentrated vertical joint loads, which are input into the system, are computed according to the following expression:

$$\text{PJVD}(i,j) = \text{TOTCDL}(i,j) + \text{REDCLL}(i,j) - \text{TOTCDL}(i-1,j) - \text{REDCLL}(i-1,j) - (\text{PW}(i,j)\text{RL}(j) + \text{PW}(i,j-1)\text{RL}(j-1))/2.0 \tag{5}$$

where,

PJVD(i,j) = the concentrated vertical joint load applied to the jth joint in the ith story.

The values of PJVD(i,j) and PW(i,j) are used in the following expression to compute the column gravity loads:

$$\text{AXC}(k,j) = \sum_{i=1}^{k} \text{RLD1}(\text{PJVD}(i,j) + (\text{PW}(i,j-1)\text{RL}(j-1) + \text{PW}(i,j)\text{RL}(j))/2.0 \tag{6}$$

where,

AXC(k,j) = the total factored column gravity load which reflects column live load reduction.

RLD1 = gravity load factor for plastic design.

Note that column live load reduction is not considered in the computation of column gravity load and moments.

The joint and girder loads described above compose the gravity load condition. The lateral concentrated loads, which require no special refinement prior to input, are combined with the gravity load condition to form the gravity plus wind loading condition.

Note, again, the loading condition input data for the existing system, PW(i,j) and PJVD(i,k) are generated only after extensive hand manipulation of raw structural loading data according to expressions one through five. This is an extremely undesirable state, especially for tall buildings.

To relieve the user of this work load, making the system more attractive, the existing design system programming which controls the input of loading condition data and computation of factored column gravity loads is changed in PLADS I to allow the input of what the user considers to be actual dead and live concentrated vertical joint working loads and dead and reduced live uniform beam working loads plus the column live load reduction coefficients, from all of which factored gravity column axial loads are computed to reflect live load reduction. The following is a description of the methodology used by this programming change to implement this state.

1. The user specifies the column live load reduction factors. The user may specify zero factors if he

is designing, for example, a library or a hospital in which case it is very likely that the maximum live load will act over a given bay simultaneously.

2. The user is then required to input uniformly distributed beam dead and live loads BEAMDL(i,j), BEAMLL (i,j). It is the user's responsibility to refine this input to reflect his desired loading state which may include live load reduction. These loads are used to automatically compute the gravity beam loading condition by the following expression:

$$PW(i,j) = BEAMDL(i,j) + BEAMLL(i,j) \tag{7}$$

3. The total column dead and live loads and reduced column live loads are automatically computed using expressions (2), (3), and (4), where JOINTDL(i,j) and JOINTLL(i,j) and RCC(i,j) are required input by the user.

4. The factored column gravity load condition is automatically computed using the following expression:

$$AXC(k,j) = \sum_{i=1}^{k} (TOTCDL(i,j) + REDCLL(i,j))RLD1 \tag{8}$$

5. The lateral loads are not refined in any way. The lateral loading condition is directly input into the existing system as horizontal concentrated loads applied to the external joints of the frame. In the analysis and design procedures, these lateral loads are considered to act on the frame alternately from both the left and right

sides.

Summarizing, this programming change to improve system handling of loading condition data allows the user to input basic working load data in the form of BEAMDL(i,j), BEAMLL(i,j), JOINTDL(i,k), JOINTLL(i,k), and RCC(i,k). These data are then automatically refined by the system to form the gravity loading condition in the form of PJVD(i,k) and PW(i,j) and the gravity plus lateral loading condition, which will automatically reflect column live load reduction in plastic design.

<u>Consideration of Column Elongation and Shortening in the Calculation of Delta for the P-delta Effect</u>

The existing plastic design part incorporates a plastic design method for the factored combination gravity plus wind load condition. This design method includes the computation of the relative story deflections of a failure mechanism to be used in the consideration of the P-delta effect. The method of computing the relative story deflection of a failure mechanism used by the existing plastic design part considers only lateral deflections due to beam and column bending and brace elongation, neglecting effects due to column elongation and shortening which could be significant in the ultimate load failure mechanism. In the interests of obtaining a more accurate representation for delta to be used in the P-delta effect computations, the computation of the relative story deflections at the collapse mechanism is revised to include consideration of the effects due to column elongation and shortening.

Before this programming change is described, a brief review of the existing method for calculating delta for the P-delta effect is in order.

In the existing system, when each panel in a story is required to be an unbraced panel, delta is taken as the maximum of the mechanism deflections for each panel in the story. The existing method does not consider the influence of beam and column axial deformation.

When one or more penals in a given story may contain braces, the relative panel deflection due to brace elongation at the yield strain is computed for each panel where bracing is permitted.

The relative deflection of a braced panel is computed as the deflection occuring at the time the brace reaches its yield state. This is a conservative definition since the design equations employed in the existing plastic design method require the maximum brace stress to be less than or equal to 85% of the yield stress.

The relative deflection of a braced panel is calculated using the following equation (see Ref. 5, p. 219):

$$\text{DELTA}(i,j) = \frac{\sigma_y L^2{}_B(i,j)}{EL(j)}$$

where,

σ_y = the brace yield stress.

$L_b(i,j)$ = the brace length in the jth panel of the ith story.

$L(j)$ = the length of the jth bay.

E = the modulus of elasticity.

The relative deflection of an unbraced panel is calculated on the basis of the most current plastic moment diagrams and beam and column section properties. The method used is the slope deflection method applied to the subassemblage of a story (for a more detailed description of this method refer to Reference 12, Chapter 14). Each story subassemblage consists of an upper story panel beam and a windward panel column. The relative deflection will be calculated at the time immediately after the formation of the collapse mechanism; consequently, the slope deflection method can be applied to the deflections calculation. A summary of the equations for calculating delta for this case follows.

For lateral load from the left,

$$\frac{\mathrm{DELTA}(i,j)}{h(i)} = \mathrm{THETA}(i,j) - \frac{h(i)}{3EI_c(i,j)}\left[M_{ct}(i,j) - \frac{M_{cb}(i,j)}{2}\right] \quad (10)$$

where,

$$THETA(i,j) = \frac{M_{bl}(i,j)L'(j)}{3EI_b(i,j)}\left[1 - \frac{d_c'(i,j)}{4L(j)}\right] - \tag{11}$$

$$\frac{M_{br}(i,j)L'(j)}{6EI_b(i,j)}\left[1 + \frac{d_c'(i,j)}{2L(j)}\right] + \frac{LAMBDA_2\ P_w(i,j)L'(j)^2}{8EI_b(i,j)}$$

$$\left[1 + \frac{d_c'(i,j)}{L_c'(j)}\right]$$

For lateral load from the right,

$$DELTA(i,j) = THETA(i,j+1) - \frac{h(i)}{3EI_c(i,j+1)} \tag{12}$$

$$\left[M_{ct}(i,j+1) - \frac{M_{cb}(i,j+1)}{2}\right]$$

where,

$$THETA(i,j+1) = THETA(i,j) - \tag{13}$$

$$2\left\{\frac{LAMBDA_2 P_w(i,j)L'(j)^2}{8EI_b(i,j)}\left[1 + \frac{d_c'(i,j)}{L'(j)}\right]\right\}$$

and,

DELTA(i,j) = panel (i,j) relative story deflection.

$d_c'(i,j)$ = average column depth in panel (i,j).

E = modulus of elasticity.

h(i) = height of story (i).

$I_b(i,j)$ = moment of inertia of beam (i,j).

$I_c(i,j)$ = moment of inertia of column (i,j).

L(j) = length of bay (j).

$L'(j) = L(j) - d_c'(j)$ = clear span length of beam (j).

$LAMBDA_2$ = load factor for the combination gravity plus wind loading condition.

$M_{br}(i,j)$ = beam (i,j) right joint moment.

$M_{cb}(i,j)$ = column (i,j) bottom joint moment.

$M_{ct}(i,j)$ = column (i,j) top joint moment.

$P_w(i,j)$ = equivalent concentrated load applied at midspan of beam (i,j).

THETA(i,j) = beam (i,j) rotation at plastic hinge.

There are aspects of this procedure which are conservative and others which are unconservative. It is conservative in the sense that the maximum shear capacity of the panel is not yet reached when the shortest brace yields. It is unconservative that the effects of column elongation and shortening are neglected in the calculation of delta. Execution of some example design problems using the existing plastic analysis and design system (5) demonstrate that for braced stories delta is an order of magnitude smaller than for unbraced stories and, accordingly, axial deformations of columns can be relatively important. The AISC specifications (2) recommend that these deformations be considered; therefore, the programming revision, described below, is implemented in order that these deformations may, on the user's request, be considered in the computation of delta for the P-delta effect.

<u>Programming Changes to Include Column Elongation and Shortening in the Computation of Delta for the P-delta Effect.</u> During the existing plastic anaylsis and design

a large number of relative story displacements are computed and in the interests of efficient use of computer time, an approximate method for computing the relative story displacement, delta, due to column axial deformations is included. The approximate method for calculating delta due to column axial forces has been developed in the existing system where it is used in the elastic stiffness design method for the approximate lateral deflection analysis for relative story deflections due to column elongation and shortening (see Ref. 5, p. 282). This method is applicable here by simply revising the equations to include effects of the column axial forces for the frame at the ultimate load. The equations are summarized below and for a detailed development of the method refer to Reference 5. The delta due to column axial deformations is calculated using the following equations.

$$\mathrm{DELTA}_c(i,j) = \frac{h(i)}{N-1} \sum_{k=i+1}^{M} \sum_{j=2}^{N} \left[\frac{H_1+H_2+H_3}{W(k,j-1)+W(k,j)} \right] \quad (14)$$

where,

M = number of stories.

N = number of bays + 1

$$H_1 = \frac{-\,T(k,j-1)W(k,j)}{A_c(k,j-1)L(j-1)}$$

$$H_2 = \frac{T(k,j)}{A_c(k,j)} \left[\frac{W(k,j-1)}{L(j-1)} - \frac{W(k,j)}{L(j)} \right]$$

$$H_3 = \frac{T(k,j+1)}{A_c(k,j+1)} \frac{W(k,j)}{L(j)}$$

and,

$A_c(k,j)$ = cross sectional area of column (k,j).

$T(k,j) = F_c(k,j)h(k)/E$

$W(k,j) = \frac{1}{2}(V_c(k,j) + V_c(k,j+1)) + \bar{R}(k,j)$

where,

$\bar{R}(k,j)$ = horizontal component of tension brace force in the panel from the exact matrix stiffness analysis reviewed in the first part of this chapter.

$V_c(k,j)$ = column end shear from exact matrix stiffness analysis.

$F_c(k,i)$ = column axial force from exact matrix stiffness analysis.

<u>Improvement of the Convergence Characteristic of the Elastic Stiffness Design When Gravity Sway Deflections are Critical</u>

During the execution of example design problems for the purpose of testing the existing computer design system, a difficulty was generated in the elastic stiffness design process. This problem may be described as follows.

The example problem (see Ref. 5, Ex. No. C9.1A) during which this difficulty arose was the design of a twenty-four story, three bay, unbraced, rectangular steel frame. The maximum elastic stress for the elastic stress design part was specified as the yield stress and the relative deflections limit specified was delta/h $\leq$ 1/400.

All columns above and including story nine and all beams were designed using A36 steel with a yield stress of 36 ksi. All columns below and including story 10 were designed using A441 steel with a yield stress of 50 ksi.

At the end of the plastic design part the total design weight of the structure was 132.4 tons. At this point two executions of the elastic stiffness design, which was described in the early part of this chapter, were completed, after each of which an exact matrix stiffness analysis of the redesigned frame showed a favorable decrease in relative story deflections relative to the increase in structural weight. During these two executions of the elastic stiffness design part only one column changed size while all other member property changes occured in the beams of bay two. After the second elastic stiffness design, new values of the exact relative story deflections were calculated and a few of these values still exceeded the specified maximum of 0.36 in. Because of this, a third cycle of the elastic stiffness design was executed producing column size increases in column line three of stories 14 and 16 as well as beam size increases in several stories of bay two. Following this cycle, a new set of exact relative story deflections were calculated and it was discovered that extremely large changes in the gravity sway deflections resulted in several realtive story deflection values to exceed the maximum permissible values by amounts larger than in the previous cycle for both wind from the left and wind from the right.

The reason for these large gravity sway deflections was that the third execution of the elastic stiffness design resulted in numerous highly localized member property changes, described above, generating a highly unsymmetrical stiffness configuration which in turn lead to the large gravity sway deflections. It is at this point in the elastic stiffness design process that the gravity sway deflections begin to control the design. The total design weight of the frame after the third cycle of the elastic stiffness design was 145.3 tons.

The large influence of the gravity sway deflections resulted in two more cycles of the elastic stiffness design before the imposed relative story deflection limits were satisfied. This put the final design weight of the structure at 192.4 tons.

In an effort to improve the efficiency of the elastic stiffness design process and reduce the weight of frames which may possibly exhibit large gravity sway deflections due to the generation of unsymmetrical stiffness configurations, a programming change to the existing elastic stiffness design was performed.

Since the existing elastic stiffness design method does not attempt to minimize gravity sway deflections when modifying members, it is necessary to incorporate such consideration into the existing elastic stiffness design computer programs. The programming revision to do this must be focused at what seems to be the heart of the gravity sway problem, and that is the generation of an unsymmetrical stiffness configuration for the frame during the elastic stiffness design process. The programming change to the existing elastic stiffness design method attempts to solve this problem by employing a scheme by which only half of the panels in a particular story are considered at any time during the execution of the elastic stiffness design. This is accomplished by revising the existing optimization technique to determine the minimum deflection sensitivity coefficient for the members in the panels of only half of the story under consideration until the appropriate relative story deflections for the given story under consideration do not exceed the maximum permissible relative story deflection for that story. A given story is divided in half to form a left and right panel subassemblage according to the following description.

In the case of a frame with an even number of bays, the left panel subassemblage in a story consists of all of the panels to the left of the column line which divides the frame longitudinally in half, with an equal number of panels to the right and left of this column line. The right panel subassemblage is defined analogously.

In the case of a frame with an odd number of bays, the left panel subassemblage in a story consists of the panel which divides the frame in the same manner as the column line described above, plus all of the panels to the left of this panel. An analogous definition exists for the right panel subassemblage. The Figures 1 and 2 illustrate how a frame is divided in half to form a left and right panel subassemblage for each story for the cases in which a frame has an even number of bays and an odd number of bays.

It should be noted that the middle of a particular story is defined with reference to the number of bays and not the center of gravity of stiffness of the panels in a given story; therefore, it is important to realize that the method described above may not give favorable results for all cases of this gravity sway problem. However, the author feels that the example problem used to study the case is of a practical nature sufficient to merit the employment of the method described herein.

Implementation of the Strong Column - Weak Beam Design Constraint

In regions where wind and siesmic forces may have a significant effect on the behavior of a structure, it has become standard practice to provide reserve lateral strength. When rigid frames are designed to provide earthquake and wind load resistance this reserve lateral

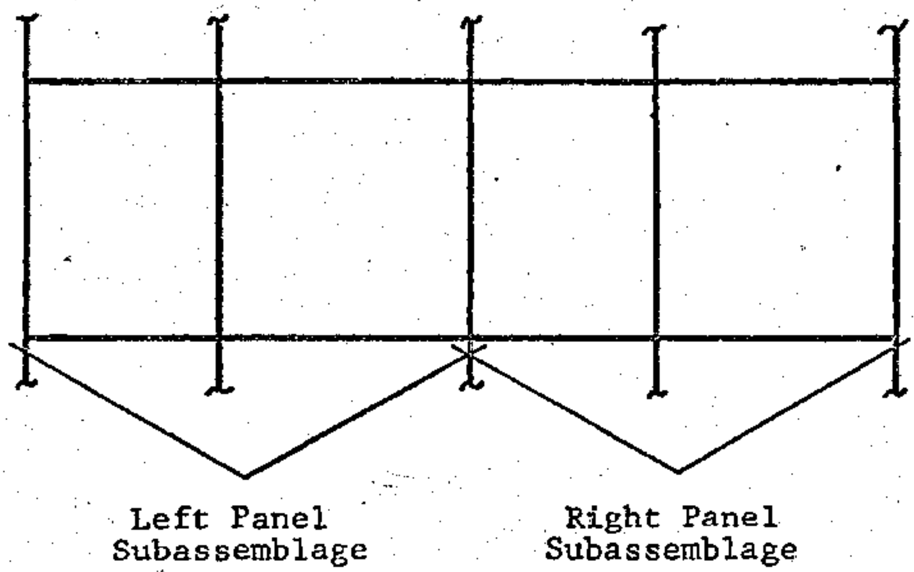

Figure 1. Panel Subassemblages for a frame with an Even Number of Bays.

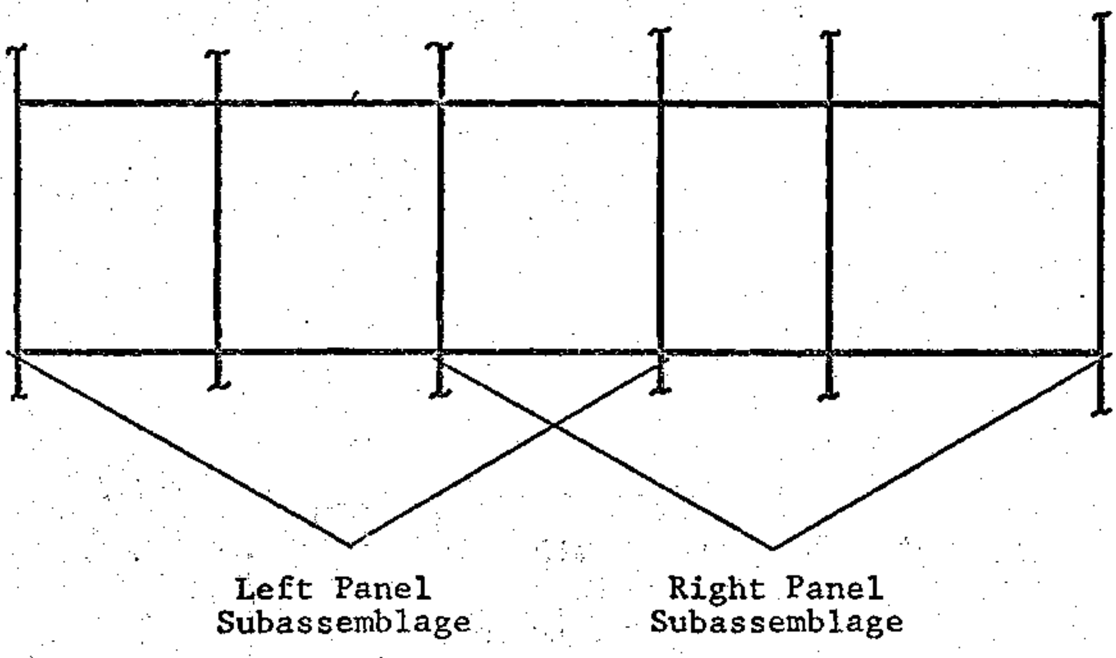

Figure 2. Panel Subassemblages for a Frame with an Odd Number of Bays.

strength stems from the ability of the joints to form plastic hinges.

In the design of frames where reserve lateral strength is an important consideration, a prime design objective is to insure overall frame stability. Consideration must be given to the effect on frame stability of each component and of the interrelationship between members. Probably the first concern is the proper proportioning of girders and columns with respect to each other, and it is advisable, and has become standard practice, to proportion members so that plastic hinges will form in beams rather than columns. When considerable yielding may occur, plastic hinge formation in columns may lead to more severe effects on frame stability than hinge formation in beams.

To provide reasonable assurance that plastic hinges will form in beams rather than columns, a method is incorporated into the existing plastic analysis and design part to satisfy what is referred to as the strong column - weak beam design constraint. This constraint is satisfied by insuring that the sum of the reduced plastic moment capacities of the columns framing into a particular joint exceeds the sum of the reduced plastic moment capacities of the beams framing into the same joint. Thus, at each joint in the frame the following constraint must be satisfied.

$$2[\,CMP1(i,j)\,] = BMP(i,j) + BMP(i,j+1) \quad (15)$$

and $$2[\,CMP2(i,j)\,] = BMP(i,j) + BMP(i,j+1) \quad (16)$$

where,

$$BMP(i,j) = \left[1.0 - \frac{P(i,j)}{P_{cr}(i,j)}\right]\left[1.0 - \frac{P(i,j)}{P_e(i,j)}\right]$$

$\frac{M_m(i,j)}{C_m}$, the reduced plastic moment capacity of the jth beam in the ith story, based on Eq. 2.4-2, Ref. 2, where

$M_m(i,j)$ = maximum moment that can be resisted by the beam in the absence of axial force as computed by Eq. 2.4-4, Ref. 2.

$P(i,j)$ = axial force in the jth beam of the ith story.

$P_e(i,j)$ = defined in Section 2.4, Ref.2.

$P_{cr}(i,j)$ = ultimate strength for axially loaded compression member.

C_m = factor defined in Section 1.6.1, Ref. 2.

$CMP1(i,k) = \left[1.0 - \frac{P(i,k)}{P_y(i,k)}\right]1.18M_p$, reduced plastic moment capacity of the kth column in the ith story. Eq. 2.4-3, Ref. 10. Where,

$M_p(i,k) = Z(i,k)T_y(j,k)$

$P_y(i,k) = T_y(i,k)A_c(i,k)$

$T_y(i,k)$ = yield stress of kth column in the ith story.

$Z(i,k)$ = plastic section modulus for the kth column in the ith story.

$A_c(i,k)$ = cross-sectional area of kth column in ith story.

$CMP2(i,k) = (1.0-P(i,j)/P_{cr}(i,j))(1-P(i,j)/P_e(i,j))M_m(i,j)/C_m$, reduced plastic moment capacity of the kth column in the ith story, Eq. 2.4-2, Ref. 2, with all parameters defined exactly as above only in this case for columns.

The factor of 2 used in Equation 15 reflects the fact that it is common construction practice to include a column splice above a given joint.

The method for satisfying the strong column - weak beam design constraint consists of a computer program which redesigns the columns framing into each joint if $2(CMP1) \geq BMP(i,j) + BMP(i,j+1)$ and $2(CMP2) \geq BMP(i,j) + BMP(i,j+1)$. This column size changing process operates on the columns at each joint in every story starting from the top story and proceeding downward to successively lower stories. The methodology employed by the design process to satisfy the strong column - weak beam design constraint is described as follows.

1. At the joint under current consideration, a check is made to determine if the sum of the reduced plastic moment capacities of the columns framing into that joint exceeds the sum of the reduced plastic moment capacities of the beams framing into that joint.

2. If $2(CMP1)$ and $2(CMP2) \leq BMP(i,j) + BMP(i,j+1)$ at the joint under consideration, then the strong column -

weak beam design constraint is satisfied at this joint and the method proceeds to the next joint.

3. If 2(CMP1) and/or 2(CMP2) ≥ BMP(i,j) + BMP(i,j+1) at the joint under consideration, the lower column framing into that joint is redesigned by retrieving the next largest column section with the smallest weight increase from the column section table.

If 2(CMP1) and/or 2(CMP2) ≥ BMP(i,j) + BMP(i,j+1), then the lower column framing into the joint is redesigned according to the process just described.

This column design process described in this step continues until the strong column - weak beam design constraint is satisfied at this joint, at which time the method proceeds to the next joint to be considered.

4. When the strong column - weak beam constraint has been satisfied at every joint in a story, the column design process goes to the joints in successively lower stories until this constraint is satisfied at every joint in every story.

For both braced and unbraced frames the satisfaction of the strong column - weak beam constraint is a user specified option. In both the existing design system and the proposed ICES PLADS I subsystem, the plastic analysis and design methods allow the user to specify the manner by which the panels of each story will resist the ultimate story shear. For an unbraced frame, all of the panels in every story will resist ultimate story shear by panel moment action and in this case it is advisable that the user specify the satisfaction of the strong column - weak beam constraint. For a braced frame, the strong column - weak beam constraint may not be as necessary.

If the user specifies that the unbraced panels in the stories of a braced frame may, through panel moment action, contribute to the ultimate story shear resistance of the stories, the user may or may not want to satisfy the strong column - weak beam design constraint depending on the degree to which the unbraced panels contribute to the ultimate shear resistance of a story. If the user determines, through a trial plastic analysis and design execution of his problem, that the unbraced, moment resisting panels make a significant contribution to the shear resistance of a given story, he should specify the satisfaction of the strong column - weak beam constraint because the stability of the columns framing into the moment resisting joints of the unbraced panels may be appreciably affected, especially in the case of tall buildings. Otherwise, it is advisable, and certainly will result in overall design weight savings, to ignore the strong column - weak beam design constraint.

Revised Approximate Lateral Deflection Analysis to Include the Implementation of an Exact Solution Method to a Linear Tridiagonal Systim of Simultaneous Equations

The existing elastic stiffness design part includes a method for the approximate analysis of relative story deflections, superimposing effects of beam and column bending and brace elongation, and column elongation and shortening.

The existing elastic stiffness design method is employed to design the members of a rectangular plane framed structure according to user imposed lateral deflection constraints. The design process includes member property increases in order to decrease the relative story deflections if they exceed a specified maximum. These member property changes are made in a way which minimizes the cost increase for an incremental decrease in relative story deflection.

Due to the large number of lateral story deflection calculations made during the elastic stiffness design process, it is not practical in terms of computer time to employ each time an exact matrix stiffness analysis to compute these lateral deflections; therefore, it was necessary that the existing approximate lateral deflection analysis methods were developed.

These approximate analysis methods are amenable to optimization techniques employed by the existing elastic stiffness design processes; however, they are still inefficient and furthermore, inaccurate to a greater degree than seems necessary mainly due to the approximate method of solving the linear system of simultaneous equations generated by the approximate lateral deflection analysis for the effects of beam and column bending and brace elongation.

To improve the efficiency and accuracy of the approximate analysis of the relative story deflections due to beam and column bending and brace elongation (and hence the efficiency and accuracy of the total approximate analysis package), the method of computing the relative story deflections is revised to include a solution based on an exact method of solving a system of tri-diagonal equations.

The formulation of the approximate analysis of relative story deflections due to beam and column bending and brace elongation results in the following equation (see Ref. 5, Ch. 5).

$$\mathrm{DELTA}_s(i) = (1.0/\ (1.0 + EA_i^{\prime}K_{is}\,Q_i))(A_iK_{is} + B_iK_{is1} + C_iK_{is2} - \mathrm{DELTA}_s(i-1)EB_i^{\prime}K_{is1}Q(i-1) - \mathrm{DELTA}_s(i+1)\ EC_i^{\prime}K_{is2}Q(i+1)) \tag{17}$$

where,

$$K_{is0} = 4/\sum_j K_c(i,j) + 1/\sum_j K_b(i,j) + 1/\sum_j K_b(i+1,j)$$

$$K_{is1} = 1/\sum_j K_b(i,j)$$

$$K_{is2} = 1/\sum_j K_b(i+1,j)$$

$$Q_i = L^2(j)A_{br}(i,j)/L_b{}^3(i,j)$$

$$A_i = S(i)h^2(i)/48E$$

$$B_i = S(i-1)h(i-1)h(i)/48E$$

$$C_i = S(i+1)h(i+1)h(i)/48E$$

$$A_i' = h^2(i)/48E$$

$$B_i' = h(i-1)h(i)/48E$$

$$C_i' = h(i+1)h(i)/48E$$

$S(i)$ = the total shear applied to the ith story.

$K_b(i,j)$ = the stiffness of the jth beam in the ith story.

$= I_b(i,j)/L(j)$

$K_c(i,j)$ = the stiffness of the jth column in the ith story.

$= I_c(i,j)/h(i)$

$L(j)$ = the length of the jth bay.

$I_b(i,j)$ = major axis moment of inertia of jth beam in ith story.

$I_c(i,j)$ = major axis moment of inertia of jth column in ith story.

$L_b(i,j)$ = the length of the X bracing in the jth panel in the ith story.

$A_{br}(i,j)$ = the cross-sectional area of the X bracing in the jth panel in the ith story.

h(i) = the height of the ith story.

E = the modulus of elasticity of steel.

The application of Eq. 17 to each story of the frame results in a system of M equations in the M unknown relative story deflections. The existing plastic analysis and design system employs an approximate solution to this set of equations based on successive substitutions as follows.

1. Eq. 17 written for story one results in $DELTA_s(1)$ as a function of $DELTA_s(2)$ as well as member properties in story one.

2. Eq. 17 written for story two results in $DELTA_s(2)$ as a function of $DELTA_s(1)$, $DELTA_s(3)$ and member properties in story two.

3. $DELTA_s(1)$ is substituted into Eq. 17 written for story two and then solved for $DELTA_s(2)$. The result is $DELTA_s(2)$ as a function of $DELTA_s(3)$ and member properties in stories one and two.

4. Eq. 17 written for story three results in $DELTA_s(3)$ as a function of $DELTA_s(2)$, $DELTA_s(4)$ and member properties in story three.

5. $DELTA_s(2)$ is substituted into Eq. 17 written for story three which is then solved for $DELTA_s(3)$. The results is $DELTA_s(3)$ as a function of $DELTA_s(4)$ and member properties of stories one, two and three.

6. At this point the assumption is made that terms relating to influences of three or more stories away are negligible and thus may be omitted. Consequently, $DELTA_s(3)$ is a function of $DELTA_s(4)$ and member properties of stories two and three.

7. Eq. 17 written for story four results in $DELTA_s(4)$ as a function of $DELTA_s(3)$, $DELTA_s(5)$ and member properties of story four.

8. $DELTA_s(3)$ is substituted into Eq. 17 written for story four which is then solved for $DELTA_s(4)$. The result is $DELTA_s(4)$ as a function of $DELTA_s(5)$ and member properties of stories two, three and four.

9. The assumption made in step 6 is applied to $DELTA_s(4)$. Consequently, $DELTA_s(4)$ is expressed as a function of $DELTA_s(5)$ and member properties only in stories two, three and four.

10. The procedure is continued, story by story, down the frame to the bottom story. DELTA (M) is expressed only as a function of member properties in stories M and M-1.

By back substitution, all other story deflections may be obtained.

It is evident that the use of this method to compute approximate relative story deflections may produce results below the level of accuracy which should be maintained throughout the elastic stiffness design process because the computation of a given relative story deflection does not consider the effects of the members at least three stories away on either side of the story under consideration. The programming change described below was implemented to correct this inaccuracy.

The programming change to the existing method of computing approximate relative story deflections due to beam and column bending and brace elongation incorporates a modified Gauss Reduction solution to the tridiagonal system of MxM equations generated by applying Eq. 17 to each story of the frame under design.

Rearranging Eq. 17 to get all $DELTA_s$ terms on the left side results in the following expression:

$$DELTA_s(i+1)EC_i'K_{is2}\ Q(i+1) + (1.0 + EA_i'K_{is0}Q(i))DELTA_s(i) + EB_i'K_{is1}Q(i-1)DELTA_s(i-1) = (A_iK_{is1} + B_iK_{is1} + C_iK_{is2}). \quad (18)$$

Applying Eq. 18 to every story of the given frame results in the following tridiagonal system of M equations in the M unknown relative story deflections.

$$\begin{bmatrix} A11(1) & A7(1) & 0 & 0 & \cdots & 0 \\ A8(2) & A11(2) & A7(2) & 0 & \cdots & 0 \\ 0 & A8(3) & A11(3) & A7(3) & \cdots & 0 \\ \cdot & & & & & \\ \cdot & & & & & \\ \cdot & & & & & \\ 0 & 0 & 0 & A8(M-1) & A11(M-1) & A7(M-1) \\ 0 & 0 & 0 & 0 & A8(M) & A11(M) \end{bmatrix} \begin{bmatrix} DELTA_s(1) \\ DELTA_s(2) \\ DELTA_s(3) \\ \\ \\ \\ DELTA_s(M-1) \\ DELTA_s(M) \end{bmatrix} = \begin{bmatrix} A6(1) \\ A6(2) \\ A6(3) \\ \\ \\ \\ A6(M-1) \\ A6(M) \end{bmatrix} \quad (19)$$

where,

$$A11(i) = (1.0 + EA_i^{\prime}K_{is0}Q(i))$$

$$A6(i) = (A_iK_{is0} + B_iK_{is1} + C_iK_{is1})$$

$$A7(i) = EC_i^{\prime}\ K_{is2}Q(i+1)$$

$$A8(i) = EB_i^{\prime}K_{is2}Q(i-1)$$

Eq. 19 is solved using a Gauss Reduction technique modified to take advantage of the fact that only the three-element diagonal of each row need be operated on.

What follows is a brief review of a generalized Gauss Reduction technique for solving a system of linear simultaneous equations, followed by a description of the same Gauss Reduction technique modified to account for the need only to operate on non-zero elements of the banded diagonal of the tridiagonal system of equations. It is this technique which is employed to solve the tri-diagonal system of M equations in the M unknowns generated by applying Eq. 18 to the M stories of the frame under consideration.

Consider the following linear system of M equations in M unknowns.

$$\left[\begin{array}{cccccc|c} a(1,1) & a(1,2) & a(1,3) & \ldots & a(1,M-1) & a(1,M) & b(1) \\ a(2,1) & a(2,2) & a(2,3) & \ldots & a(2,M-1) & a(2,M) & b(2) \\ a(3,1) & a(3,2) & a(3,3) & \ldots & a(3,M-1) & a(3,M) & b(3) \\ \vdots & \vdots & \vdots & & \vdots & \vdots & \vdots \\ a(M,1) & a(M,2) & a(M,3) & & (M,M-1) & a(M,M) & b(M) \end{array}\right] \quad (20)$$

where the A matrix is the coefficient matrix and the B vector is the right-hand-side vector.

The following equations describe the generalized Gauss Reduction technique for transforming Eq. 20 into an upper triangular matrix.

$$a^{(k)}(i,j) = a^{(k-1)}(i,j) - a^{(k-1)}(k,j)(a^{(k-1)}(i,k)/a^{(k-1)}(k,k)) \tag{21}$$

where $k = 1,M-1$; $i = k+1,M$; $j = k+1,M+1$, describing row operation on A and

$$b^{(k)}(i) = b^{(k-1)}(i) - b^{(k-1)}(k)(a^{(k-1)}(i,k)/a^{(k-1)}(k,k)) \tag{22}$$

where $k = 1,M-1$; $i = k+1,M$; $j = M+1$, which describes row operations on B.

The results of operating on the elements of the rows of Eq. 20 using Eqs. 21 and 22 is the following upper triangular matrix.

$$\left[\begin{array}{cccccc|c}
a(1,1) & a(1,2) & a(1,3) & \ldots & a(1,M-1) & a(1,M) & b(1) \\
0 & a'(2,2) & a(1,3) & \ldots & a'(2,M-1) & a'(2,M) & b'(2) \\
0 & 0 & a'(3,3) & & a'(3,M-1) & a'(3,M) & b'(3) \\
\vdots & \vdots & \vdots & & \vdots & \vdots & \vdots \\
0 & 0 & 0 & & 0 & a'(M,M) & b'(M)
\end{array}\right] \tag{23}$$

where the $a'(i,j)$ and $b'(i)$ signify that these elements have been operated on by Eqs. 21 and 22 respectively.

Eq. 23 is a solvable form of Eq. 20 and the solution vector X may be obtained by applying the following back substitution equations to Eq. 23.

$$x(M) = b'(M)/a'(M,M) \tag{24}$$

$$x(j) = (1/a'(j,j))(b'(j) - \sum_{k=j+1}^{M} a'(j,k)x(k)) \tag{25}$$

where j = M-1, M-2, ..., 1.

The previous development provides a background for the following description of the method by which the generalized Gauss Reduction method is modified and applied to Eq. 19.

Referring back to Eq. 19, the generalized Gauss Reduction method is modified to account for the fact that Eq. 19 describes a tridiagonally banded system of equations and as such, we need only operate on the non-zero elements of each row in order to solve this system.

Consider the following general banded system:

where AX = C

$$A = \begin{array}{c} \\ W \\ \\ \\ \\ \\ \\ \\ \end{array} \begin{bmatrix} x & x & x & x & o & o & o & o \\ x & x & x & x & x & o & o & o \\ x & x & x & x & x & x & o & o \\ x & x & x & x & x & x & x & o \\ o & x & x & x & x & x & x & x \\ o & o & x & x & x & x & x & x \\ o & o & o & x & x & x & x & x \\ o & o & o & o & x & x & x & x \end{bmatrix} \tag{26}$$

As shown, A represents a diagonally banded matrix with a band width of W. To modify the generalized Gauss Reduction Equations 21, 22, 24, 25 we must only modify the indexing parameters to operate only on non-zero row elements follows.

For the reduction procedure:

$$a^{(p)}(i,j) = a^{(p-1)}(i,j) - a^{(p-1)}(k,j) \tag{27}$$

$(a^{(p-1)}(i,j)/a^{(p-1)}(k,k))$

where,

$p = 1, M-1$

$i = k+1,\ k+W-1;\ k+W-1 \leq M$

$j = k+1,\ W+i-1;\ W+i-1 \leq M$

$$c^{(k)}(i) = c^{(k-1)}(i) - c^{(k-1)}(k)(a^{(k-1)}(i,k)/a^{(k-1)}(k,k)) \qquad (28)$$

and where,

$k = 1, M-1$

$i = k+1,\ k+W-1;\ \ k+W-1 \leq M$

$j = M+1$

These operations on the rows of A and C reduce this set of equations to a solvable, upper triangular form A' and C' as before. Back substitution is accomplished as follows:

$$x(M) = c'(M)/a'(M,M) \qquad (29)$$

$$x(j) = (1/a'(j,j))(c'(j) \sum_{k=j+1}^{M} a'(j,k)x(k)) \qquad (30)$$

where

$j = M-1,\ M-2\ ,\ \ldots,\ M-W+1$

$$x(j) = (1/a'(j,j))(c'(j) - \sum_{k=j+1}^{j+W-1} a'(j,k)x(k)) \qquad (31)$$

where

$j = M-W,\ M-W-1 \ldots,\ 1.$

Applying Equations 28, 29, 30 and 31 to Eq. 19

where W=2, reduces this set of equations to an upper triangular system of equations which may be solved for the M unknown relative story deflections.

Execution of design examples shows that as well as providing an exact and more accurate method of computing approximate relative story deflections due to beam and column bending and brace elongation, a time savings of approximately 20 per cent during the elastic stiffness design is realized by the implementation of this change to the approximate analysis package.

Some Minor Programming Changes

The following is a brief point by point discussion of several minor programming changes to the existing plastic design algorithms in order that they remain consistent with guidelines set down by the 1970 AISC Manual of Steel Construction (2).

1. The existing plastic design method allows the design of members in completely unbraced stories; however, effective column length factors used are equal to 1.0 which is only a valid assumption when columns in braced stories are considered. This is corrected by the inclusion of a routine to compute effective length factors for columns in unbraced stories according to the method described in Section 1.8 of Ref. 2.

2. The C_m factor used in AISC column interaction Eq. 2.4-2 used in the existing plastic design method was

computed only according to the formula $C_m = 0.6 - (0.4) \cdot (M1/M2) \geq 0.4$ described in Article 1.6.1 of the 1970 AISC Manual of Steel Construction (2). This computation is broadened by including logic which considers $C_m = .85$ in unbraced stories.

3. For the purpose of comparing design results obtained by the original design system to design results described by Lehigh University in Ref. 12, column axial force design was constrained by a condition that the column axial force may not exceed the ultimate column axial force computed as the product of the column yield stress times the column cross-sectional area. To be consistent with the latest AISC (2) requirements, this design constraint was changed so that the column axial force caused by the factored gravity plus factored horizontal loads may not exceed 85 per cent of the ultimate column axial force.

4. In the existing plastic design system, factored gravity plus lateral load design stresses were obtained by increasing the actual stresses due to this load case by 33 1/3 per cent. This incorrect computation was removed because this increase is considered by the use of the 1.3 lead factor for the factored gravity plus lateral load case.

CHAPTER III

THE STRUCTURE, PHILOSOPHY AND USE OF THE ICES PLADS I PROBLEM-ORIENTED LANGUAGE (POL)

Introduction

The major effort and main purpose of this Thesis is the presentation of a new subsystem of ICES, the Plastic Analysis and Design System (PLADS I) which is described in this chapter. ICES PLADS I is developed from the existing computerized plastic analysis and design system including the programming changes described in CHAPTER II. The analysis and design optimization methods employed in the existing computer programs are used in PLADS I and remain basically unchanged; however, the programs are rewritten to include ICETRAN programming concepts.

A POL is also developed to allow the engineer user to interact flexibly with the system, controlling the design problem input, the analysis and design processes, and the output of the design results. By allowing the engineer user to interact more freely with the system, the POL lends the PLADS I subsystem a completely new user-oriented philosophy with capabilities enhanced significantly over those of the existing plastic analysis and design system.

Besides a description of the PLADS I subsystem, this chapter will also give a description of the ICES basic software package in order to provide some insight into the capabilities which will be given to the existing plastic analysis and design system by the POL and the ICETRAN programming language.

An Overview of ICES PLADS I Internal Organization

The ICES system enables engineers with little or no computer programming experience to use the computer to aid in solving engineering problems. ICES consists of a set of computerized engineering subsystems, each of which is designed to aid in the solution of a particular type of engineering problem. ICES PLADS I is such a subsystem designed to aid the engineer in solving problems related to the plastic analysis and design of multistory steel frames.

Internally, ICES PLADS I consists of a group of computer program load modules, written in the ICETRAN programming language which is a major extension of FORTRAN. ICETRAN allows access to the ICES system programming capabilities which provide for the most efficient use of the computer's main and secondary storage space and which is essential when handling large amounts of computer coding and engineering data as is the case with

PLADS I.

The PLADS I subprograms are linkage-edited to form edited relocatable modules which are the smallest program units that are transferrable between main and secondary storage areas during execution. This structure is particularly well suited to PLADS I because the non-overlayed FORTRAN version of this program cannot operate in less than 100,000 words of main core on a UNIVAC 1108; while the overlayed FORTRAN version, segmented to operate in 60,000 words, is highly inefficient in terms of I/O time.

Associated with the set of PLADS I edited load modules is the PLADS I POL consisting of a set of commands or requests which is interpreted by the computer to communicate the engineer's problem solving needs to the computer. The POL allows the user to input structural data to be applied to any number of problem solving capabilities. It was designed to reflect the current language an engineer might use to discuss a plastic design problem with a colleague.

Almost all of the PLADS I data is handled by dynamic arrays which possess a treelike structure completely defined by a series of pointers. Only the base pointer of each array occupies a fixed location in main core. Storage locations for the remaining pointer and data levels are assigned by the ICES executive program at the time of execution. When necessary, low priority data may be automatically transferred to secondary storage until needed. Due to the design of the PLADS I data structure, which was not altered in the conversion from FORTRAN to ICETRAN, it was necessary to define most of the PLADS I dynamic arrays initially as high priority, and released when necessary, in order to achieve maximum data handling efficiency. For a more detailed overview of ICES, see Ref. 15.

The ICES PLADS I Problem Oriented Language

With the above background description of the basic composition and operation of the ICES PLADS I subsystem, this chapter continues with a description of the PLADS I POL, (i.e., the POL convention, the POL command structure, and the capabilities provided by the POL commands). The PLADS I POL structure is divided into four distinct categories: (1) commands to initialize a PLADS I problem; (2) commands for PLADS I data input; (3) PLADS I design and analysis directives; and (4) commands to specify the output of results.

PLADS I Language Conventions

The engineer user communicates with PLADS I using a series of commands or requests. While the engineer user must choose from terms recognized by the PLADS I subsystem to form his commands, these terms do reflect the current language used in engineering practice. Each

PLADS I command either supplies data to be used by the subsystem programs or specifies some operations to be performed on the data already specified, or both.

PLADS I commands are composed of four basic elements; words, alphanumerics, integers and real numbers. A description of these four elements follows.

Words are terms and single letters which have meaning to the PLADS I subsystem. These terms and single letters are used to aid the engineer user in modelling a plastic design problem in a language convenient to use and easily understood by the engineer. As was mentioned earlier, these terms are not chosen by the engineer, but are contained in the PLADS I subsystem POL dictionary and are recognized by the subsystem. Examples:

1. MAXIMUM — This is the first word of one the commands which is used to describe some numerical data to the subsystem.
2. D, FY — These are one and two letter words which are recognized by the PLADS I subsystem and occur as numerical data descriptors within several of the commands.

Alphanumerics are data value names that the engineer chooses to use. These are composed of letters, digits and blanks and must be enclosed in single quotation marks to distinguish them from word types as described above.

Examples:

'16WF24,' 'PLADS Test Problem'

Integers are data value numbers that do not contain decimal points.

Examples:

2, 49, -888, +10000

Note that integers may not contain decimal points as in 9.0 or commas as in 6,385. If the sign of an integer is not specified it is assumed to be plus (+).

Decimals are data value numbers that must contain a decimal point. A decimal number may be written in one of two basic formats:

1. Normal decimals which consist of digits, a decimal point and an optional sign which, if not specified, is assumed to be plus (+).

Examples:

-6.73, +492.3, 6.999

2. Exponential numbers are decimal numbers multiplied by a power of ten.

Examples:

-67.3E-1, 4.923E2, .6999E+1

Conventions in the Use of the PLADS I POL

The most efficient method by which problem data may be communicated to PLADS I is by punching the needed commands and data on computer punch cards (a teletype machine used in an interactive mode may also be used to input necessary data into PLADS I, but this is an inefficient method since PLADS I is not yet efficiently constructed for interactive mode communications with the computer).

Using PLADS I, all 80 columns of a punch card may be used, and up to 320 columns may be used to communicate a given piece of data by punching a minus (-) sign preceded by at least one blank space and followed by one or more blank spaces to the end of the card from which the continuation is made. Each new command must start on a new card. Command data elements are separated from other data elements by commas, spaces, or both. A number of spaces and commas together is treated as a single space.

Just as it is very helpful for a FORTRAN programmer to place comment cards throughout his program in order to clarify logic he is following, it is also very helpful for the PLADS I user to intersperse comments among the other commands of a PLADS I job. This capability is allowed by placing a dollar sign ($) in column one of the comment card followed by one or more blank spaces and then the comment. Comments may also be placed in the middle of the card following a command by preceding the comment by a dollar sign, preceded and followed by at least one blank space. A comment may also be used on a card that is to be continued by placing the dollar sign, preceded and followed by at least one blank space and the comment, following the continuation hyphen.

When specifying problem data to the PLADS I subsystem, it is very often useful to list elements in a group. Most of the POL commands in the PLADS I subsystem refer to a symbol "list." A list in PLADS I is a set of integers separated by spaces or commas or a set of consecutive integers written in the form n_1 to n_2. A list may contain only a set of integers corresponding to a specific entity being described, such as bay lengths, story heights, concentrated joint loads, etc. List notation is described as follows:

$$\text{"list"} = \left\{ \begin{array}{l} i_1,\ i_2,\ i_3,\ \ldots,\ i_n \\ i_1 \left\{ \begin{array}{c} \underline{\text{TO}} \\ \\ \underline{\text{THROUGH}} \end{array} \right\} i_2 \\ \underline{\text{ALL}} \end{array} \right\}$$

where i_1, i_2, i_3, ..., i_n refer to an integer list such as 1, 9, 10, 15 and i_1 TO/THROUGH i_2 refers to a set of consecutive integers such as 3 TO 8, and ALL refers to the complete set of elements being treated by a particular command.

Example:

LOADING CONCENTRATED, STORIES ALL, JOINTS ALL, —

DL 0.01, LL 0.44

Here, the dead and live working concentrated joint loads are being specified for all of the joints in all of the stories of the frame being designed.

The notation used for integer, real and alphanumeric elements is described in the following table.

Table 1. Symbol Key

Symbol	Explanation
i_1, i_2, ...	Integers
v_1, v_2, ...	Real Numbers
'a_1', 'a_2', ...	Alphanumerics - always enclosed in single quotes
list	This refers to the list of integers described above

As was noted before, the PLADS I POL commands are made up of certain words and symbols recognized by the PLADS I subsystem. In all cases the words which compose the different commands may be abbreviated. In the description of the commands that follows, the minimum abbreviation that will be accepted by PLADS I will be underlined in the command listing. For example, one of the commands uses the word <u>MAX</u>IMUM; but only the word MAX is necessary and is sufficient to be recognized by PLADS I.

In many of the command listings, a series of elements will be enclosed in braces as follows:

$$\left\{ \begin{array}{l} \underline{\text{BE}}\text{AMS} \\ \underline{\text{COL}}\text{UMNS} \\ \underline{\text{BA}}\text{YS} \end{array} \right\}$$

This particular form indicates that any one of the words within the braces may be chosen. In the above case a word beginning with BE or COL or BA may be chosen.

In almost all of the PLADS I commands, certain words are added to clarify the meaning of the commands, but are not necessary for proper interpretation by PLADS I. These words are subsequently ignored by PLADS I and in the command listing they are enclosed in parentheses. Example:

LOAD FACTOR (DEAD PLUS LIVE) F1 v_1

In this command, the phrase DEAD PLUS LIVE does not change the meaning of the command and is actually ignored by PLADS I if it is included; however, its inclusion does add clarity by specifying the loading condition for which the F1 load factor, v_1, is specified.

An arrow located in front of an element inside a set of braces indicates that if a choice is not made, the the element indicated by the arrow will be assumed.

Example:

$$\text{DEBUG} \quad \left\{ \begin{array}{l} \quad \text{OFF} \\ \quad \text{MAP} \\ \quad \text{REGISTERS} \\ \rightarrow \text{COMMON} \end{array} \right\}$$

$$\left\{\begin{array}{l}\text{POOL}\\ \text{ALL}\end{array}\right\}$$

In this command, if the user does not specify a choice, the word COMMON will be assumed to have been chosen.

In the PLADS I member properties specification command, a set of data items will be used with labels for these data items. PLADS I allows the user to specify these data items, omitting their labels, in the order specified in the command listing, or to give the data items in any order provided they are labelled.

Example:

To specify all of the member properties for a given structural element of the frame being studied, the following command is used:

$$\underline{\text{MEM}}\text{BER (}\underline{\text{PRO}}\text{PERTIES) }\underline{\text{ST}}\text{ORY list}\left\{\begin{array}{l}\underline{\text{BE}}\text{AMS}\\ \underline{\text{COL}}\text{UMNS}\\ \underline{\text{BAY}}\text{ (}\underline{\text{BR}}\text{ACING)}\end{array}\right\}\text{list -}$$

$$[\underline{\text{ID}}]\ \text{'}a_1\text{'}\ [\underline{\text{WT}}]\ v_1\ [\underline{\text{AX}}]\ v_2\ [\underline{\text{DEPTH}}]\ v_3\ [\underline{\text{IZ}}]\ v_4\ [\underline{\text{IY}}]\ v_5\ \text{-}$$
$$[\underline{\text{SZ}}]\ v_6\ [\underline{\text{ZZ}}]\ v_7\ [\underline{\text{RZ}}]\ v_8\ [\underline{\text{RY}}]\ v_9.$$

Note that 'a_1', v_1, v_2, ..., v_9 may be specified in their proper order without using the labels. Note also that if a label is used anywhere in this string of data items, all subsequent data items must have labels. As the command appears above, all the data items with their corresponding labels may appear in any order.

As was stated in CHAPTER II, the PLADS I subsystem considers the plastic design and elastic design of only plane, rectangular, braced or unbraced framed structures; thus, two-dimensional reference frames are used to describe the structural systems considered by PLADS I. In PLADS I, two separate rectangular cartesian coordinate systems are used to describe a given structural system.

The description for the structure requires the use of a global coordinate system which is fixed into the subsystem; that is, the user has no choice regarding its use. Figure 3 shows the orientation of this global rectangular coordinate system.

The description of individual member properties and the interpretation of analysis and design results depends on the use of a local coordinate system. This local coordinate system is also a permanent characteristic of the PLADS I subsystem. Figure 4 shows the orientation of the local coordinate system. Figure 5 shows the positive components of force and displacement.

Note that for all structural systems considered by the PLADS I subsystem, the individual structural elements are oriented so that their z axes are always perpendicular to the plane of this page and positive pointing up from this page.

The description of the basic ICES commands and all of the subsystem commands used to describe and execute a PLADS I design problem is according to the following

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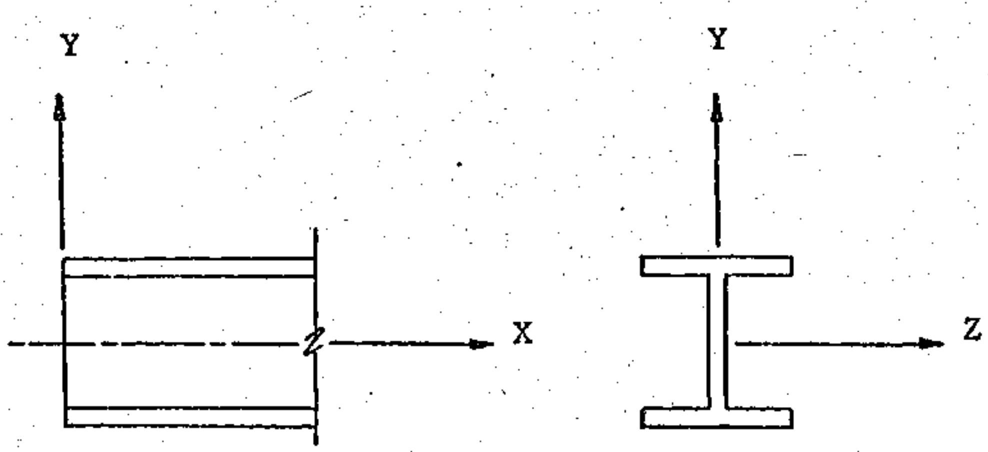


Figure 4. PLADS I Local Rectangular Coordinate System.

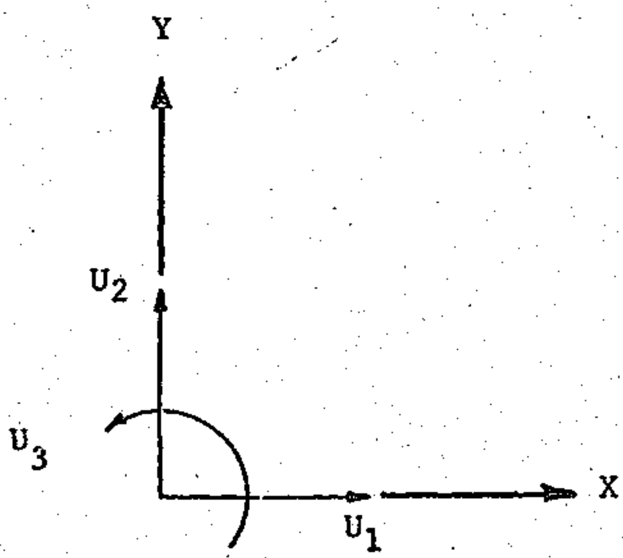


Figure 5. PLADS I Force and Displacement Sign Convention

format:

1. General form
2. Individual form
3. Elements
4. Explanation
5. Examples
6. Possible errors

The general and individual forms are the listings of the command in the forms as they may be used in the PLADS I subsystem. Each element of the command is then described in order to give the user a better understanding of what data he is trying to input to PLADS I via a particular command. An explanation then follows which describes in detail the philosophy behind the command and what operations the command initiates. Examples and possible errors are finally given to enhance the user's understanding of the command and to provide the user with some "quick" experience in the use of the command.

In addition to the PLADS I commands which are described in the remaining sections of this chapter, the ICES basic system provides a number of utility commands which apply to all ICES subsystems. These utility commands are described as follows.

1. Printer Carriage Control

General form:

EJECT

Explanation:

The EJECT command causes the printer to immediately skip to the top of the next page. This command is useful to separate different sections of a single problem or to separate different PLADS I problems grouped in a single run stream.

2. The FINISH Command

General form:

FINISH

Explanation:

The FINISH command must be the last command in a PLADS I job or any ICES job. This command allows ICES to exit from the job after all other commands are processed. Note that, in effect, the FINISH command marks a given job or run stream "dead"; therefore, after a FINISH command is encountered, the run stream is terminated and no other PLADS I problems may be processed in that particular job. Since this is the case, in a run stream where multiple PLADS I problems occur, a FINISH command may only appear at the end of the final problem in the run stream if all of the problems are to be processed.

3. ICES Dynamic Memory Management and Step Processing Timing Information

General form:

DBGTIM

Explanation:

The use of the DBGTIM command provides the user with timing information about ICES dynamic memory management and the processing of the different problem steps. The time, according to a 24-hour wall clock, is printed for the various data management operations as well as transfer of control steps. This command is especially useful as a means of following the internal operation of the ICES system during subsystem debugging.

4. A Debugging Aid

General form:

$$\text{DEBUG} \left\{ \begin{array}{l} \text{OFF} \\ \text{MAP} \\ \text{REGISTERS} \\ \rightarrow \text{COMMON} \\ \text{POOL} \\ \text{ALL} \end{array} \right\}$$

Explanation:

The DEBUG command is especially useful as an aid in debugging PLADS I programs. In the event of abnormal job termination, this command specifies the extent of the dump which is provided (Ref. 17).

<u>ICES PLADS I Subsystem Commands</u>

This section contains a listing and a detailed explanation of all the PLADS I commands which initialize a PLADS I problem, allow the user to input problem data, and control the design and analysis procedures and to specify the extent to which the design and analysis results are to be printed.

<u>PLADS I Subsystem Initialization Commands</u>. The following set of commands described are general commands. Unless otherwise indicated, they may appear anywhere in a given problem.

1. The PLADS I Problem Initiation Command

General form:

<u>PLADS</u> { \$ TITLE AND DESCRIPTOR DATA | <u>RES</u>TORE 'a_1' }

Elements:

'a_1' is a problem identifier of up to eight characters in length to be chosen by the user. Since it is alphanumeric data, it must be enclosed in single quotes (' ').

The PLADS command must be the first command of a given PLADS I problem. This command prepares the ICES system to accept the PLADS I POL input that will follow. If the command modifier, <u>RES</u>TORE, is not specified, the system assumes that the problem is a new one.

If the form PLADS RESTORE 'a_1' is specified all of the current problem data base associated with the problem identified by 'a_1' are restored. This data must have been previously saved with the SAVE command and stored on the DD4 data set assigned by the JCL. Additional commands may follow the PLADS RESTORE command.

2. Saving a PLADS I Problem for Future Reference

General form:

<u>SAVE</u> 'a_1'

Elements:

'a_1' is a one to eight character identifier which identifies the saved current problem data base of a PLADS I problem.

Explanation:

When this command is encountered in a given problem runstream, all information associated with the current state of the problem is stored on secondary storage in a data set internally identified as DD4 under the data file name 'a_1'. When the problem is resumed by the command PLADS RESTORE 'a_1', with 'a_1' being the same identifier used in a previous SAVE command, the problem resumes, in the same status and from the same point at which the SAVE command was issued.

The SAVE command terminates the processing of a particular problem at the point of its specification and no other PLADS I commands are valid unless they are preceded by another PLADS initialization command.

If current problem data is to be stored for a period of time longer than that defined by the current job, then the data set, DD4, must be saved permanently. APPENDIX III lists and explains the job control information necessary to accomplish this for UNIVAC 1100 Series ICES.

Examples:

```
PLADS $ TEST - 24 STORY BLDG
.
.
.
SAVE 'TEST'
FINISH
(Any time period off the computer)
PLADS RESTORE 'TEST'
.
.
.
FINISH
```

3. Retrieval of Run Time Information

General form:

$$\underline{\text{TIME}} \quad \left\{ \begin{array}{l} \underline{\text{BEGIN}} \\ \underline{\text{INCR}}\text{EMENT} \\ \underline{\text{PR}}\text{INT} \end{array} \right\}$$

Explanation:

The use of the TIME command allows the user to retrieve run time information about the different steps or processes which are being carried out during the course of a PLADS I problem execution.

The form TIME BEGIN, sets an internal computer time clock at 0 and starts the timing process.

The form, TIME INCREMENT, is intended to be used in a repetitive manner throughout the timing process and its purpose is to print out the elapsed wall clock (not CPU) time in seconds from the time at which the last TIME INCREMENT request was issued. This form of the TIME command should be used to separate the different processes, for which specific elapsed time information is desired.

Finally, the form TIME PRINT, is intended to end the timing process. When the TIME PRINT command is encountered, the elapsed wall clock (not CPU) time, in seconds, from the last TIME BEGIN request is printed.

Because of the structure of this command, it is not necessary to use the forms, TIME BEGIN and TIME PRINT, more than once in a particular job. It is recommended that the user issue the form, TIME INCREMENT, to retrieve all pertinent timing information about processes within his job.

Example:

```
PLADS $ PROB - TIMING TEST
TIME BEGIN
.
.
.
TIME INCREMENT
.
.
.
TIME INCREMENT
.
```

.
.
.

TIME PRINT

FINISH

PLADS Data Input Commands. This section describes the PLADS I commands which allow the user to input all of the data which describes a PLADS problem. They include the specification of structural configuration including overall structure dimensions and dimensions of individual structural elements; the specification of structural member properties which includes individual member behavior properties, a table of member properties made available for design purposes, yield stress and cost data; and the specification of loading condition data and design parameters. The commands are described as follows:

1. Specification of the Number of Stories and Bays

General form:

$$\underline{\text{NUM}}\text{BER } (\underline{\text{OF}}) \begin{Bmatrix} \underline{\text{STO}}\text{RIES} & i_1 \\ \underline{\text{BAY}}\text{S} & i_2 \end{Bmatrix}$$

Elements:

i_1 and i_2 are integers which give the exact number of stories and bays in the rectangular frame being considered by the problem.

Explanation:

Data from these commands, i_1 and i_2, are used to define the sizes of the dynamic arrays which store all of the input data from the other PLADS input commands; therefore, in order to accomplish successful completion of data input, this command must precede all other PLADS data input commands and design and analysis directive commands. It is recommended that the NUMBER OF STORIES and NUMBER OF BAYS commands be issued immediately following the PLADS command for new problem initiation. If a PLADS problem is restored from saved status via the PLADS RESTORE command, then the NUMBER OF STORIES and NUMBER OF BAYS commands need not be issued unless they have not been issued in the problem when it was defined and saved. If another PLADS data input command is issued and the NUMBER OF STORIES and NUMBER OF BAYS commands have not been given or ICES detected a syntax error in their issuance, the following error massage is output and the scanning mode is entered, i.e., all following commands are scanned for syntax errors but any further execution of PLADS system programs is inhibited.

> ***** ERROR -- NUMBER OF BAYS OR NUMBER OF STORIES HAS NOT BEEN PROPERLY INPUT INTO SYSTEM. SCANNING MODE IS ENTERED. *****

All of the PLADS data input commands which follow the NUMBER OF STORIES and NUMBER OF BAYS commands contain "list" and integer elements which reference specific structural elements in the frame being considered; for example, the command YIELD STRESS STORIES $list_2$ BEAMS $list_1$

FY v_1 specifies the yield stress of the beam elements referenced by list $_1$ in the story elements referenced by $list_2$. In order to input data properly so that execution of the PLADS system design and analysis computer programs will yield meaningful results, it is necessary to follow a systematic schedule for labelling the stories, bays, beams, joints and columns of the structure under consideration.

Naturally, this systematic schedule must be compatible with the manner in which the PLADS system computer programs operate on the input data, and since the only structure type presently considered by PLADS is a rectangular plane frame, the systematic labelling schedule is a fixed characteristic of the system. This labelling schedule is described below.

(a) Stories are numbered sequentially from story 1 at the top level to story n at the bottom level. The number n must correspond to the number of stories specified in the NUMBER OF STORIES command.

(b) Bays are numbered sequentially in each story from bay 1 at the left end of each story to bay n at the right end of each story. The number of bays, n, must correspond to the number of bays specified in the NUMBER OF BAYS command.

(c) Columns and joints are likewise numbered sequentially in each story from column or joint 1 at the left end of each story to column or joint k at the right end of the story. The number k is set within the PLADS I system and is equal to n + 1, where n is equal to the number of bays specified in the NUMBER OF BAYS command.

2. Specification of Bay Lengths

General form:

BAY (LENGTHS)

list v_1

.
.
.

list v_n

Individual form:

BAY list [LENGTH] v_1

Elements:

list is an integer list containing those bays in a particular structure under consideration which are being assigned a length by this command.

v_1 through v_n are real number data elements and represent the values of the lengths being assigned to the bays referred to in the element list. The input units for BAY LENGTHS must be in inches and, as data elements, the labels beginning with the letter "L" may be omitted.

Explanation:

The BAY LENGTH command is used to specify the lengths of the bays or panels of the structure in the problem being considered by the engineer user. Since only rectangular structures are being considered, specification of bay lengths is equivalent to assigning joint-center-to-joint-center lengths to the beams in the structure. It is assumed that the length of a given bay refers to the distance between the center lines of two adjacent column lines and is the same for all stories in the bay.

Examples:

An example of the tabular form of specifying bay lengths is as follows.

```
BAY LENGTHS
          1  4  5  8   144.0
          2  3  6  7   288.0
```

The bay lengths may also be specified by the individual form of the command which is illustrated by the following example.

```
BAYS 1 TO 5 LENGTH 167.0
```

Possible errors:

All of the bays in a given structure must necessarily be assigned a length or an error condition will occur. The failure to assign a length to a particular bay may result from neglecting to include all of the bay label numbers in the "list" elements of the command, or by having a syntax error in a BAY LENGTH command. An example of an error of this sort follows.

```
BAYS 'A'. 'B', 'C', 'D' LENGTH 120.0
```

In this example the bays are labelled A, B, C, and D. Letter labels for bays are invalid. As was pointed out in the explanation of the NUMBER OF BAYS command, all bays are labelled from left to right by consecutive numbers from 1 up to the number of bays specified in this BAY LENGTHS command. If all the bays are not properly assigned a length, the following error message will be printed out prior to the time execution of the design and analysis system programs would be invoked.

***** ERROR -- ALL BAY LENGTHS HAVE NOT BEEN INPUT PROPERLY. EXECUTION WILL BE TERMINATED. *****

Note that as a result of this error, further execution of the problem in which it occurs is terminated.

3. Specification of Story Heights

General form:

STORY (HEIGHTS)

list v_1

.
.
.

list v_n

Individual form:

STORY list [HEIGHT] v_1

Elements:

As in the BAY LENGTHS command, list also implies an integer list referring to those stories in a particular structure being assigned a height value.

v_1 is a real number representing the height assigned to the stories referenced in the "list" element and labelled by a word beginning with the letter "H" which may be omitted. The units for story heights must be <u>inches</u>.

Explanation:

The STORY HEIGHT command completes the set of those commands which are necessary to define the geometric configuration of the structure to be considered by PLADS. Similar to specification of bay lengths, it is assumed the height of a given story is defined as the distance between the center lines of two adjacent beam lines. And again, since PLADS I only considers rectangular frames, the specification of story heights is analogous to the specification of column lengths from joint center to joint center.

Examples:

As shown by the command listing above, the STORY HEIGHTS command may be written as a tabular command or an individual command. Examples of these two types follow.

(a) Tabular form:

```
STORY HEIGHTS
      1, 2, 5 TO 9   HEIGHT 180.0
      3, 4, 10   HEIGHT 144.0
```

(b) Individual form:

```
STORIES ALL HEIGHT 180.0
```

Possible errors:

The structure of the STORY HEIGHT command is exactly the same as that of the BAY LENGTH command; therefore, errors in the BAY LENGTH command, as described above, also apply to the STORY HEIGHT command. If all of the stories are not properly assigned a height value, further execution is inhibited and the following error message is printed.

***** ERROR -- ALL STORY HEIGHTS HAVE NOT BEEN INPUT PROPERLY. EXECUTION WILL BE TERMINATED.*****

Figure 6 is a schematic representation of how a structure will appear to PLADS I after the correct use of the NUMBER OF STORIES, NUMBER OF BAYS, STORY HEIGHTS and BAY LENGTH commands.

Note that for all structures considered by PLADS I all the supports are assumed to be fixed and all the joints are assumed to be rigid.

4. Member Section Table Command

General form:

$$\underline{\text{SEC}}\text{TIONS} \quad \left\{ \begin{array}{l} \underline{\text{TOT}}\text{AL } (\underline{\text{NUM}}\text{BER}) \\ \underline{\text{E}}\text{CONOMY} \\ \underline{\text{BR}}\text{ACING} \end{array} \right\} \begin{array}{l} \left\{ \begin{array}{l} \underline{\text{BEA}}\text{MS} \\ \underline{\text{COL}}\text{UMNS} \end{array} \right\} i_1 \\ \qquad\qquad\quad\; i_2 \end{array}$$

(list of section names and properties)

Elements:

i_1 is an integer number representing either the total number of beam or column sections or total number of economy beam or column sections to be input depending

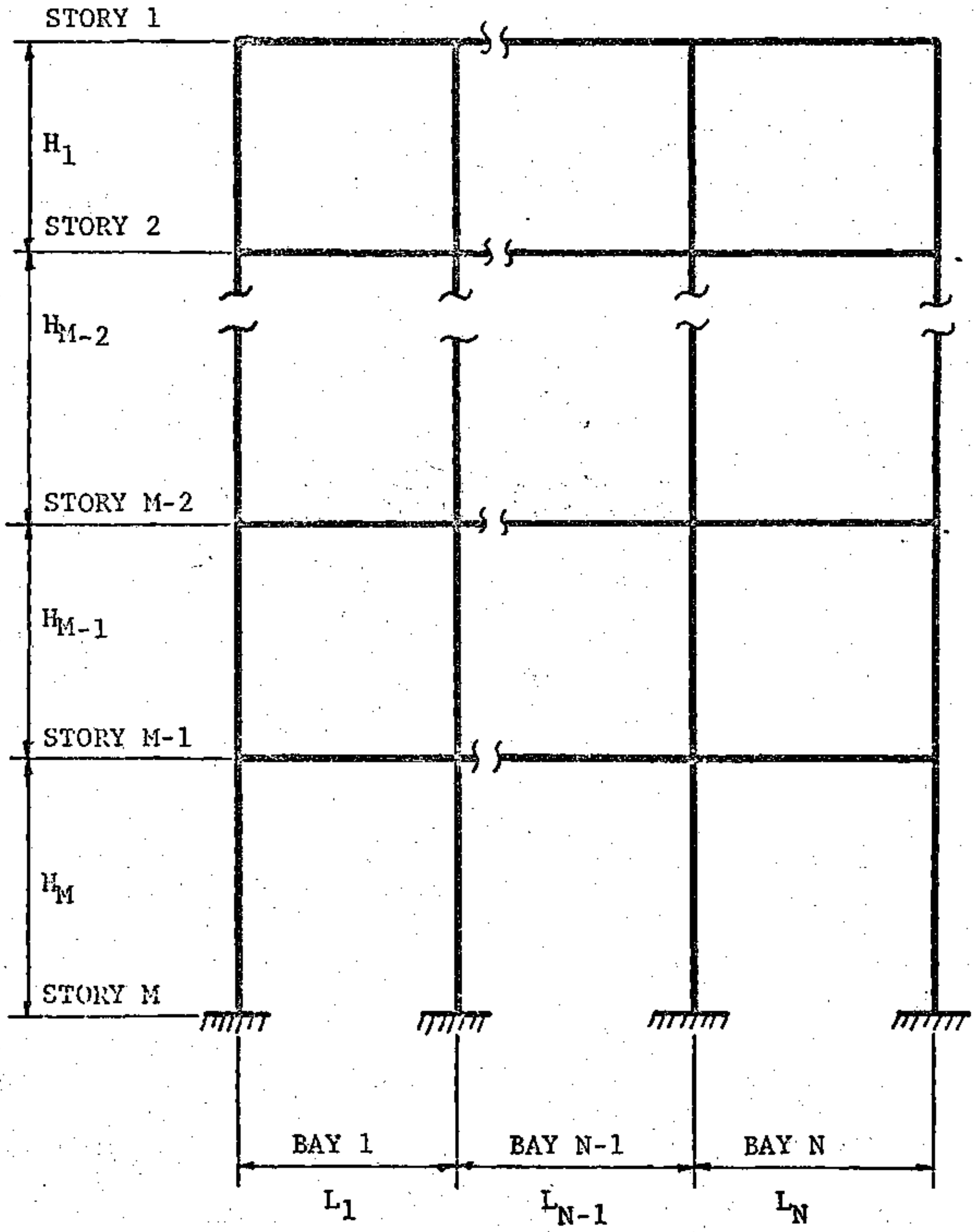


Figure 6. A Typical PLADS I Frame.

on which form of the command is used.

i_2 is also an integer representing the total number of bracing sections to be input.

The list of section names and properties is a table of member section names and properties punched on computer data cards. This table is expected to follow the command forms SECTIONS TOTAL NUMBER BEAMS, SECTION TOTAL NUMBER COLUMNS, and SECTIONS BRACING. No such table is expected to follow the ECONOMY forms of the command. Failure to comply with this format will result in an error condition.

Each of the beam and column section table entries consists of the following information punched on one computer data card. The physical units represented by this data and required format are in parentheses to the right of the data element listed.

(a)	Section name (Alphanumeric)	(2A4)
(b)	Section unit weight (lb/ft)	(F8.1)
(c)	Cross-sectional area (in^2)	(F6.2)
(d)	Depth (in)	(F6.2)
(e)	Major axis moment of inertia (in^4)	(F11.1)
(f)	Minor axis moment of inertia (in^4)	(F11.1)
(g	Elastic section modulus (in^3)	(F8.1)
(h)	Plastic section modulus (in^3	(F8.1)
(i)	Major axis radius of gyration (in)	(F7.2)
(j)	Minor axis r dius of gyration (in)	(F7.2)

The number of data card entries comprising the beam and column section tables must correspond to the number, i_1, specified in the SECTIONS TOTAL NUMBER form of the command, and on each of these cards, the ten data elements, enumerated above, must be punched according to the format (2A4, F8.1, 2F6.2, 2F11.1, 2F8.1, 2F7.2).

Each element of the bracing section table consists of the following information also punched on one computer card and again, the physical units represented by these data and required format are enclosed in parentheses to the right of the data element listed.

(a) Section name (Alphanumeric) (2A4)

(b) Section unit weight (lb/ft) (F8.1)

(c) Cross-sectional area (in^2) (F8.2)

Here again, the number of computer data cards comprising the bracing section table must correspond to the number, i_2, specified in the SECTIONS BRACING form of the command, and on each of the cards the bracing data elements listed above must be punched in the format (2A4, F8.1, F8.2).

Explanation:

The SECTIONS command allows the user to generate a table of beam, column and bracing section properties. These section property tables are extremely important to the PLADS I design system because it is from these tables, during the design processes, that new members are selected.

The sections which should be used to compose the beam, column and bracing member property tables may consist of the appropriate series of rolled sections for beams, columns and braces. As suggested by the structure of the command, the beam and column section tables may be composed of two parts, an economy and a non-economy part. The SECTIONS ECONOMY form of the command for both beams and columns specifies that the first i_1 sections of the beam or column section table are to be ordered on increasing cross-sectional areas and increasing major axis plastic section modulus without regard to beam or column depth constraints (a command for specifying depth constraints will be described in the following sections of this chapter). Note that the beam and column economy section tables should consist of any series of the sections tabulated in bold face type in the Plastic Design Selection Table on page 14, Section 2 of the AISC Manual of Steel Construction (2). These sections are the lightest possible sections which satisfy a required major axis plastic section modulus requirement. This section of the table for both beams and columns is required and must be accounted for by the specification of the SECTIONS ECONOMY command. The non-economy beam and column tables are accounted for by the fact that the user may specify, using the SECTION TOTAL NUMBER form of the command, a total number of beam and column sections greater than the number of economy sections. The number by which the total number of sections specified exceeds the number of economy sections specified is the number of beam and/or column sections in the non-economy table. The non-economy beam and column sections are ordered on increasing major axis plastic section modulus and are used when beam and column depths are critical. Non-economy section tables consist of any series of rolled steel sections (tabulated in light-faced type in the Plastic Design Selection Table on page 14, Section 2 of Ref. 2). If used, these sections will be the lightest sections which satisfy both a major axis plastic section modulus and user-imposed maximum member depth requirement. Note that the number of economy beam and column sections may be specified equal to the total number of beam and column sections. This implies that the non-economy section table may be omitted.

The bracing section table is a one part table and must be input following the SECTIONS BRACING command. This table may consist of any series of available rolled bracing sections ordered on increasing area.

Note that the order of issue of the different section commands is irrelevant and that their placement in a particular data input stream is insignificant as long as they are issued preceding any design and analysis directives.

The beam, column and bracing section tables used in the example problems are shown in APPENDIX I.

Examples:

(a) SECTIONS BEAM ECONOMY 40

SECTIONS BEAM TOTAL NUMBER 40

(table input)

In example (a), the total number of beam sections is specified as 40. The number of economy beam sections si also specified as 40; therefore, the section table which will follow the latter of the above two commands will consist only of 40 economy beam sections ordered on increasing area and increasing plastic section modulus without regard to depth.

(b) SECTIONS COLUMN ECONOMY 40

SECTIONS COLUMN TOTAL NUMBER 88

(table input)

In example (b), a column section table totalling 88 members is specified, the first 40 of which are economy column sections. The second 48 members of this column section table are the non-economy column sections.

(c) SECTIONS BRACING 20

(table input)

Example (c), demonstrates the input of a bracing sections table consisting of 20 bracing sections ordered on increasing area.

Possible errors:

Besides any number of command syntax errors, the following errors are likely to occur.

(a) The specification of the number of economy sections merely states the number of the first elements in the specified section table which must be ordered on increasing area without regard to member depth. No section table input may follow this command or the following ICES Basic System error message is printed out.

```
****  INPUT WARNING 7.08
      COMMAND NOT COMPLETELY PROCESSED
****  SYMBOLS IN COMMAND INPUT NOT YET PROCESSED
      FOLLOW

****  list                               ***
```

This error condition arises when the ICES Command Interpreter attempts to interpret the section table input data which is meant to be read by an ICETRAN READ statement in an ICETRAN PLADS I subsystem program which is invoked by the command which specifies the total number of beam, column or bracing sections. Note again that section table input may only follow the command specifying the total number of beam, column or bracing sections.

(b) When the total number of a type of section is specified, the number of section table data input cards which follow this command must be equal to the number of sections specified in the command. If this is not the case, an abnormal termination of the problem execution will occur.

(c) If a syntax error occurs in any of the SECTION commands or any of their specifications are neglected, the following error message will be printed.

***** ERROR -- THE BEAM/COLUMN/BRACING SECTION TABLE IS NOT PROPERLY INPUT INTO SYSTEM. EXECUTION WILL BE TERMINATED. *****

5. Individual Member Property Specification

General form:

$\underline{\text{MEM}}\text{BER} \ (\underline{\text{PROP}}\text{ERTIES})$

$$\underline{\text{ST}}\text{ORY list}_1 \left\{ \begin{array}{l} \underline{\text{BE}}\text{AMS} \\ \underline{\text{COL}}\text{UMNS} \\ \underline{\text{BAY}} \ (\underline{\text{BR}}\text{ACING}) \end{array} \right\} \text{list}_2 \left\{ \begin{array}{l} \text{section values} \\ \underline{\text{TAB}}\text{LE i} \end{array} \right\}$$

$$\vdots$$

$$\underline{\text{ST}}\text{ORY list}_1 \left\{ \begin{array}{l} \underline{\text{BE}}\text{AMS} \\ \underline{\text{COL}}\text{UMNS} \\ \underline{\text{BAY}} \ (\underline{\text{BR}}\text{ACING}) \end{array} \right\} \text{list}_2 \left\{ \begin{array}{l} \text{section values} \\ \underline{\text{TAB}}\text{LE i} \end{array} \right\}$$

Individual form:

$$\underline{\text{MEM}}\text{BER} \ (\underline{\text{PROP}}\text{ERTIES}) \ \underline{\text{ST}}\text{ORIES list}_1 \left\{ \begin{array}{l} \underline{\text{BE}}\text{AMS} \\ \underline{\text{COL}}\text{UMNS} \\ \underline{\text{BAY}} \ (\underline{\text{BR}}\text{ACING}) \end{array} \right\}$$

$$\text{Section values} = \left[\underline{\text{ID}}\right] \ \text{'}a_1\text{'} \ \left[\underline{\text{WT}}\right] \ v_1 \ \left[\underline{\text{AX}}\right] \ v_2 \ \left[\underline{\text{D}}\text{EPTH}\right] \ v_3 \ \left[\underline{\text{IZ}}\right] \ v_4 \ \left[\underline{\text{IY}}\right] \ v_5 \ \left[\underline{\text{SZ}}\right] \ v_6 \ \left[\underline{\text{ZZ}}\right] \ v_7 \ \left[\underline{\text{RZ}}\right] \ v_8 \ \left[\underline{\text{RY}}\right] \ v_9$$

Elements:

list_1 and and list_2 are two integer lists referring to the beams, columns or bay bracing named in list_2 of the stories named in list_1 which are being assigned member properties.

'a_1' is an alphanumeric name of up to eight characters in length. This name is a section identifier and is optional and may be omitted.

v_1 is the section unit weight and must be input with the units of lb/ft.

v_2 is the cross-sectional area of the section and must be input with units of in^2.

v_3 is the depth of the section whose input units must be in.

v_4 is the major axis moment of inertia and is relative to the local z axis according to the coordinate systems described in the first part of this chapter. IZ must be input with units of in^4.

v_5 is the minor axis moment of inertia with respect to the local y axis and has the input units of in^4.

v_6 is the elastic section modulus with respect to the local z axis and has the units of in^3.

v_7 is the plastic section modulus with respect to the local z axis and has the units of in^3.

v_8 is the radius of gyration with respect to the local z axis and has the units of in.

v_9 is the radius of gyration with respect to the local y axis and has the units of in.

i is the integer designating the ith element in the beam, column or bracing section table, whichever is applicable. This number must be between one and the number of beam, column or bracing table sections.

Explanation:

This command is used to assign member properties individually to every member of a given structure under consideration by PLADS I.

An initial member property configuration must be generated using the MEMBER PROPERTY command if elastic design, elastic stiffness analysis or approximate analysis is invoked without having completed at least one plastic design cycle. Because of the structure of the Plastic Design part, as described in CHAPTER II, initial member properties need not be assigned prior to its execution.

The use of this command assumes that all members are prismatic; however, the different properties do not have to correspond to any specific type of section commercially available, such as wide flange members. Any member may be prismatically modelled, either by specifying each property individually or using the TABLE FORM of the command to specify the properties of a member in the appropriate section property table.

Possible errors:

The execution of elastic design and elastic analysis prior to the successful completion of at least one plastic design cycle requires the specification of an initial member property configuration for the structure under consideration. Failure to do this will result in an error condition with the following error message printed

out.

***** INITIAL BEAM/COLUMN SECTION PROPERTIES NOT INPUT PROPERLY. EXECUTION WILL BE TERMINATED. *****

Note that an error condition due to an improper bracing configuration, input may not be explicitly pointed out by PLADS I and does not preclude the occurance of an error. Syntax errors notwithstanding, it is the responsibility of the user to make certain that his bracing configuration input is correct.

6. Specification of Member Yield Stresses

General form:

$$\text{\underline{YIEL}D (\underline{STRE}SS \underline{CONF}IGURATION)}$$

$$\text{\underline{ST}ORY list}_1 \left\{\begin{array}{l}\text{\underline{BE}AMS}\\ \text{\underline{COL}UMNS}\\ \text{\underline{BA}Y (\underline{BR}ACING)}\end{array}\right\} \text{list}_2 \left[\underline{\text{FY}}\right] v_1$$

$$\vdots$$

$$\text{\underline{ST}ORY list}_1 \left\{\begin{array}{l}\text{\underline{BE}AMS}\\ \text{\underline{COL}UMNS}\\ \text{\underline{BA}Y (\underline{BR}ACING)}\end{array}\right\} \text{list}_2 \left[\underline{\text{FY}}\right] v_n$$

Individual form:

$$\underline{\text{YIE}}\text{LD (}\underline{\text{STR}}\text{ESS }\underline{\text{CONF}}\text{IGURATION) }\underline{\text{STO}}\text{RY list}_1 \begin{Bmatrix} \underline{\text{BEA}}\text{MS} \\ \underline{\text{COL}}\text{UMNS} \\ \underline{\text{BAY}}\text{ (}\underline{\text{BRA}}\text{CING)} \end{Bmatrix}$$

$\text{list}_2 \ [\underline{\text{FY}}] \ v_1$

Elements:

list_1 and list_2 are integer lists referring to those beam, columns or bay bracing elements named in list_2 of the story elements named in list_1 which are being assigned a yield stress value.

$v_1, \ldots, v_n$ are the values of the yield stress in <u>ksi</u> units being assigned to those elements named in the lists. This is a labelled data element and its label, FY, may be omitted.

Explanation:

The ultimate strength of a structural member, on which the concepts of plastic design are based, is a function of the yield stress of the material from which the structural member is formed. The PLADS I system assumes that this material is steel and the yield stress specification command allows the engineer user to specify the yield stress of each of the beams, columns and bracing elements of the structure under consideration.

Examples:

(a) An example of the tabular form of the command is:

YIELD STRESS CONFIGURATION

STORIES 1 TO 13 COLUMNS ALL FY 36.0

STORIES 14 TO 24 COLUMNS ALL FY 50.0

(b) An example of the individual form of the command is:

YIELD STRESS STORIES ALL BAY BRACING ALL FY 36.0

Possible errors:

Member yield stress data is necessary to all facets of design and analysis in PLADS I. Neglecting the specification of yield stress for any beam, column or bracing elements, or the occurance of any command syntax error will result in an error condition causing the following message to be printed out at the outset of any design of analysis operation.

***** ERROR -- YIELD STRESS CONFIGURATION FOR BEAMS/COLUMNS/BRACING NOT INPUT PROPERLY. EXECUTION WILL BE TERMINATED. *****

4. Specification of Unit Material Prices

General form:

$\underline{\text{MAT}}\text{ERIAL (}\underline{\text{UN}}\text{IT }\underline{\text{PR}}\text{ICE)}$

$$\underline{\text{ST}}\text{ORIES list}_1 \left\{\begin{array}{l}\underline{\text{BE}}\text{AMS}\\ \underline{\text{COL}}\text{UMNS}\\ \underline{\text{BA}}\text{Y (}\underline{\text{BRA}}\text{CING)}\end{array}\right\} \text{list}_2 \left[\underline{\text{C}}\text{OST}\right] v_1$$

.
.
.

$$\underline{\text{ST}}\text{ORIES list}_1 \left\{\begin{array}{l}\underline{\text{BE}}\text{AMS}\\ \underline{\text{COL}}\text{UMNS}\\ \underline{\text{BA}}\text{Y (}\underline{\text{BRA}}\text{CING)}\end{array}\right\} \text{list}_2 \left[\underline{\text{C}}\text{OST}\right] v_n$$

Individual form:

$$\underline{\text{MAT}}\text{ERIAL } (\underline{\text{UN}}\text{IT } \underline{\text{PR}}\text{ICES}) \ \underline{\text{ST}}\text{ORIES list}_1 \left\{ \begin{array}{l} \underline{\text{BE}}\text{AMS} \\ \underline{\text{COL}}\text{UMNS} \\ \underline{\text{BAY}} \ (\underline{\text{BR}}\text{ACING}) \end{array} \right\}$$

$$\text{list}_2 \left[\underline{\text{C}}\text{OST}\right] \text{v}_1$$

Elements:

$list_1$ and $list_2$ are integer lists naming those beams, columns or braces in a particular story or groups of stories which are being assigned a unit price value.

v_1, ..., v_n are the values of the unit prices in <u>cents/lb</u> being assigned to those elements named in the lists. Unit prices are effected by yield stresses and construction technique.

Explanation:

The plastic and elastic design objective employed by PLADS I may be described as least cost or least weight oriented. This command allows the user to input data necessary for PLADS I to determine cost figures for a particular design.

The unit price input data should reflect not only the unit price of bulk steel, but also fabrication and erection costs. <u>An alternative interpretation of cost is simply a relative cost index relating the relative costs rather than absolute costs</u>.

Examples:

(a) An example of the tabular form of the command is:

MATERIAL UNIT PRICES

STORIES ALL BEAMS ALL COST 26.0

STORIES ALL COLUMNS ALL COST 31.0

(b) An example of the individual form of the command is:

MATERIAL PRICES STORIES ALL BAY BRACING ALL COST 25.0

Possible errors:

If the specification of unit prices for any beams, columns or bracing is neglected, or any command syntax errors occur, the following error message will be printed before plastic design is invoked.

***** ERROR -- UNIT MATERIAL COST FOR ALL STRUCTURAL ELEMENTS NOT INPUT PROPERLY. EXECUTION WILL BE TERMINATED. *****

This error condition will result in the termination of the problem execution.

The input of unit price data is not necessary if only elastic stiffness analysis will be performed.

7. Load Factor Specification

General form:

<u>LOAD</u> <u>FACTORS</u> (<u>DE</u>AD <u>PL</u>US <u>LI</u>VE) $\left[\underline{F1}\right]$ v_1 (<u>DE</u>AD-<u>PLUS</u> <u>LI</u>VE <u>PL</u>US <u>WI</u>ND) $\left[\underline{F2}\right]$ v_2

Elements:

v_1 is the non-dimensional safety factor for the gravity loading condition.

v_2 is the non-dimensional safety factor for the gravity plus wind loading condition.

Explanation:

Plastic design philosophy recognizes the redistribution of internal member forces that takes place when critical sections, or plastic hinges, form at regions fo high bending moment in a structure. It defines a structure's limit of usefulness as the ultimate load that a structure is able to carry just prior to the formation of a sufficient number of critical sections to define a collapse mechanism for the structure. This ultimate load is an indication of the strength of the structure and it exceeds the working load by the value specified by the load factors. The LOAD FACTOR command allows the user to input ultimate load factors for both the gravity and the gravity plus wind loading conditions.

Example:

LOADING FACTORS DEAD PLUS LIVE F1 1.7 DEAD PLUS - LIVE PLUS WIND F2 1.3

The American Institute of Steel Construction Specification (2) recommends the values of 1.7 and 1.3.

Possible errors:

Load factors are required data for plastic design executions. If load factor data input is neglected or a command syntax error occurs, the following error message will be printed and problem execution will be terminated.

***** ERROR -- LOAD FACTORS NOT INPUT PROPERLY.

EXECUTION WILL BE TERMINATED. *****

Load factors need not be specified for stiffness analysis, elastic stiffness and stress design because only the working loads are used in these parts of the design system.

8. Specification of Gravity Loading Conditions

General form:

$$\underline{\text{LOAD}}\text{ING} \quad \begin{Bmatrix} \underline{\text{CONC}}\text{ENTRATED} \\ \underline{\text{UNI}}\text{FORM} \end{Bmatrix}$$

$$\underline{\text{ST}}\text{ORIES list}_1 \begin{Bmatrix} \underline{\text{JO}}\text{INTS} \\ \underline{\text{BE}}\text{AMS} \end{Bmatrix} \text{ list}_2 \left[\underline{\text{DL}}\right] v_1 \left[\underline{\text{LL}}\right] v_2$$

.
.
.

$$\underline{\text{ST}}\text{ORIES list}_1 \begin{Bmatrix} \underline{\text{JO}}\text{INTS} \\ \underline{\text{BE}}\text{AMS} \end{Bmatrix} \text{ list}_2 \left[\underline{\text{DL}}\right] v_1 \left[\underline{\text{LL}}\right] v_2$$

Individual form:

$$\underline{\text{LOAD}}\text{ING} \quad \begin{Bmatrix} \underline{\text{CONC}}\text{ENTRATED} \\ \underline{\text{UNI}}\text{FORM} \end{Bmatrix} \underline{\text{ST}}\text{ORIES list}_1 \begin{Bmatrix} \underline{\text{JO}}\text{INTS} \\ \underline{\text{BE}}\text{AMS} \end{Bmatrix}$$

$$\text{list}_2 \left[\underline{\text{DL}}\right] v_1 \left[\underline{\text{LL}}\right] v_2$$

Elements:

list_1 and list_2 are integer lists naming those beams or joints in a particular story or group of stories for which a particular loading - uniform in the case of beams and concentrated in the case of joints - is defined by a given loading condition command entry.

v_1 and v_2 are the values of the dead loads and live loads, respectively, being assigned to those elements named in the lists. The units of these values must be kips for concentrated joint loads and kips/in for uniformly distributed beam loads.

Explanation:

At this time, the structure of ICES PLADS I only allows for three loading conditions - a gravity loading condition, a gravity plus lateral loading from left condition, and a gravity plus lateral loading from right condition. This command allows the user to specify the gravity loading condition which consists of dead and live uniformly distributed beam loads and concentrated vertical joint loads. It is permitted to input any pattern of gravity load for the gravity load condition.

In the command listing above, note that the LOADING command modifier CONCENTRATED corresponds to the specification of JOINT loads while the command modifier UNIFORM corresponds to the specification of BEAM loads. These two command forms are not interchangeable; that is, concentrated beam loads or uniform joint loads may not be specified. ICES PLADS I is only structured to handle uniformly distributed beam loads and concentrated vertical joint loads in the gravity load condition.

Examples:

(a) LOADING CONCENTRATED

STORIES ALL JOINTS 1 3 DL 4.0 LL 0.0

STORIES ALL JOINTS 2 4 DL 8.0 LL 1.0

(b) LOADING CONCENTRATED STORIES ALL JOINTS ALL -
DL 8.5 LL 7.0

(c) LOADING UNIFORM

STORIES ALL BEAMS ALL DL 0.06 LL 0.125

(d) LOADING UNIFORM STORIES 1 THRU 8 BEAMS ALL -
DL 0.19 LL 0.10

Possible errors:

Specification of concentrated vertical dead and live loads for beams is invalid and will result in a command syntax error condition. For example, LOADING CONCENTRATED STORIES ALL BEAMS 4 TO 7 DL 14.0 LL 0.00 will result in a syntax error message.

Note that all loadings for all joints which are not specified or whose specification results in a command syntax error will be assigned the value of 0.0.

9. Specification of the Lateral Loading Condition

General form:

LOADING LATERAL

STORIES list $\left[\underset{\sim}{Q}\right]$ v_1

.
.
.

STORIES list [Q] v_n

Individual form:

LOADING LATERAL STORIES list [Q] v_1

Elements:

list is an integer list naming those stories to which a lateral load is assigned by a particular lateral loading command entry.

v_1 is the value of the lateral load being applied to those stories named in the list. Lateral load values must have the units of kips.

Explanation:

This command allows the specification of the lateral part of the combined gravity plus lateral loading condition. The lateral loadings consist of concentrated horizontal loads applied to the external joints at the story levels of a given structure. These lateral loads may represent wind loads, earthquake loads, or any other type of lateral loading. PLADS I automatically considers the lateral loads as coming from the left and right in combination with the gravity loads thereby representing two combined loading conditions.

Examples:

(a) LOADING LATERAL
    STORIES 1 TO 13 Q 5.76
    STORIES 14 TO 24 Q 3.29

(b) LOADING LATERAL STORIES ALL Q 4.00

Possible errors:

Other than ordinary command syntax errors, no peculiar types of error conditions related to the use of the lateral load specification command exist. The stories related to those command entries in which syntax errors occur or for which no lateral load is specified purposefully or because of neglect, are assigned the value of 0.00 by default.

10. Specification of Column Live Load Reduction Factors

General form:

LIVE (LOAD REDUCTION FACTORS)

STORIES $list_1$ COLUMNS $list_2$ v_1

.
.
.

STORIES $list_1$ COLUMNS $list_2$ v_n

Individual form:

LIVE (LOAD REDUCTION FACTORS) STORIES $list_1$ - COLUMNS $list_2$ v_1

Elements:

$list_1$ and $list_2$ are integer lists naming the columns in a story or group of stories whose live load reduction factor is being specified in a particular LIVE LOAD REDUCTION command entry.

v_1, ..., v_n are the values of the live load reduction factors for the columns designated by the lists.

These values must be less than or equal to 1.00 and are non-dimensional.

Explanation:

In many building codes, allowance is made for a percentage reduction of live loads due to the unlikely possibility that the total live load will act on the structure at any given time. This command makes it possible for the user to input column live load reduction factors (LLRF). The actual column axial force due to live loads is then taken as the full live load column axial force multiplied by the factor (1-LLRC).

Possible errors:

If the column live load reduction factors are not specified less than .01, or any command syntax errors occur, the live load reduction factors for the columns affected will be set equal to 0.00.

Examples:

(a) LIVE LOAD REDUCTION FACTORS

```
STORY 1 COLUMNS ALL            0.00
STORY 2 COLUMN 1               0.192
STORY 2 COLUMN 2               0.307
STORY 2 COLUMN 3               0.384
STORY 2 COLUMN 4               0.269
STORY 3 COLUMN 1               0.384
STORY 3 COLUMNS 2, 3, 4        0.509
STORIES 4 TO 24 COLUMNS ALL    0.509
```

(b) LIVE LOAD REDUCTION FACTORS STORIES ALL COLUMNS ALL 0.36

11. Specification of Supported Joint Loads to be Included in the P-delta Effect

General form:

SUPPORTED (GRAVITY LOADS FOR THE PDELTA EFFECT)

STORIES $list_1$ JOINTS $list_2$ [DL] v_1 [LL] v_2

.
.
.

STORIES $list_1$ JOINTS $list_2$ [DL] v_1 [LL] v_2

Individual form:

SUPPORTED (GRAVITY LOADS FOR THE PDELTA EFFECT) - STORIES $list_1$ JOINTS $list_2$ [DL] v_1 [LL] v_2

Elements:

$list_1$ and $list_2$ are integer lists naming the joints in a story or group of stories whose joint support loads are being specified in a particular SUPPORTED GRAVITY LOADS command entry.

v_1, ..., v_n are the values of the supported joint loads applied to the joints designated by the lists. These are the unfactored working dead and live loads. The units of these values must be kips.

Explanation:

A complete plastically designed structure will contain bents designed only to resist gravity loads spaced between bents which are designed for the gravity plus lateral load condition plus the P-delta effect. Since the gravity load bents cannot support gravity loads acting in a laterally displaced position, the bents designed for the P-delta effect must provide this support. This command, then, allows the user to input the gravity dead and live joint loads which come from the simple bents designed exclusively for gravity loads, to be included in the computations for the lateral displacement, delta, during the design of the bents which will support the P-delta effect.

The engineer user must decide how the gravity loads which are resisted by the supported bents are distributed to the P-delta supporting bents. The SUPPORTED command is used to apply these gravity loads to this supporting bent under design by PLADS. These loads will only affect the combination lateral plus gravity load design as additional equivalent P-delta story shears to be distributed during the design process. It should be noted that the input supported gravity loads are multiplied by the load factor for combined gravity and wind load, and the live load is reduced by the live load reduction factors, before they are used by PLADS in the P-delta computation.

Example:

SUPPORTED GRAVITY LOADS FOR THE PDELTA EFFECT

STORY 1 JOINTS 1, 4 DL 62.8 LL 45.6

STORY 1 JOINTS 2, 3 DL 40.0 LL 105.4

STORIES 2 TO 21 JOINTS 1, 4 DL 128.0 LL - 45.6

STORIES 2 TO 24 JOINTS 2, 3 DL 40.0 LL - 105.4

Possible errors:

If the supported gravity loads for a given joint are not specified purposefully or because of error of neglect, or any command syntax errors occur, the supported gravity loads for the joint affected will be set to 0.00 by default.

12. Specification of Initial Relative Story Deflections for Plastic Design

General form:

ASSUMED (INITIAL RELATIVE DEFLECTION AT ULTIMATE - LOADS) STORIES list [DELTA] v_1

Elements:

list is an integer list naming those stories which are assigned an initial relative story deflection by a particular command entry.

v_1 is the value of the initial relative story deflection assigned to those story levels named in the list. These values must have the units of inches.

Explanation:

As was summarized in CHAPTER II, plastic design is accomplished by using an iteration algorithm to solve the nonlinear cost-weight optimization problem of providing a minimum cost or weight structure which satisfies all the imposed constraints. The convergence criterion for the iteration is satisfied when the ultimate relative story deflections, computed after a complete plastic design cycle, are within a specified tolerance of the ultimate relative story deflections used to modify the lateral load effects at the start of the latest design cycle. The rapidity and efficiency with which this algorithm converges to a safe design depends, in part, on the assumed initial relative story deflection configuration, and the accuracy of the engineer's initial guess of deflection at ultimate load depends on the extent of his experience. However, since there is not a large volume of experience in this area to draw upon, a good estimate of deflections at ultimate load, recommended by Lehigh University (12), is a sway delta of 0.02 X story height for stories four from the top to the basement story, and 0.005 X story height, 0.01 story height and 0.015 X story for the first, second and third stories from the top of the structure respectively.

Examples:

(a) ASSUMED INITIAL RELATIVE DEFLECTIONS

STORY 1 DELTA 0.72

STORY 2 DELTA 1.44

STORY 3 DELTA 2.16

STORIES 4 TO 10 DELTA 2.88

for a 10-story frame with all story heights of 144.0 inches.

(b) ASSUMED INITIAL RELATIVE DEFLECTIONS STORIES - 4 TO 24 DELTA 0.036

Possible errors:

If a command syntax error occurs, or the specification of the deflections at ultimate loads is not specified for a given story, the following diagnostic message will be printed.

***** NOTE -- ASSUMED INITIAL RELATIVE DEFLECTION HAS BEEN INPUT LESS THAN OR EQUAL TO 0.01 FOR STORY NO. i. A VALUE OF .0005 (STORY HEIGHT) WILL BE ASSUMED. *****

Note that this condition will also result if the initial story deflection is specified less than or equal to 0.01. In either case, PLADS I resorts to an initial relative story deflection default specification of .0005 X story height.

13. Specification of Factor for P-delta Convergence Tolerance

General form:

<u>TOL</u>ERANCE (<u>F</u>OR <u>P</u>DELTA <u>C</u>ONVERGENCE) v

Elements:

v is the value of the tolerance factor, less than or equal to 1.00, and equal to a per cent divided by 100 (i.e. 7.5% would be input at .075).

Explanation:

Another one of the more important plastic design constraints is associated with the tolerance within which the P-delta process is to converge. In addition to the initial assumed ultimate relative story deflection described in the ASSUMED command, the convergence rate also depends upon the convergence tolerance factor, v, specified using the TOLERANCE command such that

$$\left| \frac{DELTA_{(u,new)} - DELTA_{(u,old)}}{DELTA_{(u,old)}} \right| \leq v$$

where,

$DELTA_{(u,new)}$ = ultimate displacement computed after the current plastic design cycle is completed.

$DELTA_{(u,old)}$ = ultimate displacement computed at the beginning of the current plastic design cycle.

The author has experimented with different convergence tolerance values and has determined that a value of .075 or 7.5% is acceptable for most design problems, although a value of 10% is not unreasonable. It is interesting to note that in some cases a value of less than 7.5% would not permit convergence because discrete member size changes led to changes in DELTA in excess of 7.5%.

Example:

```
TOLERANCE FOR PDELTA CONVERGENCE 0.075
```

Possible errors:

The only possible error which may arise through the issue of this command results from unacceptable command syntax which subsequently results in a default value of 0.075 being set. Also, if the command is not issued, the default value of 0.075 is set.

14. Specification of Maximum Allowable Relative Story Deflections for Elastic Stiffness Design

General form:

MAXIMUM (PERMISSIBLE RELATIVE) DEFLECTIONS (AT - WORKING LOADS)

STORIES list [DELTA] v_n

.
.
.

STORIES list [DELTA] v_n

Individual form:

MAXIMUM (PERMISSIBLE RELATIVE) DEFLECTIONS (AT - WORKING LOADS) STORY list [DELTA] v_n

Elements:

list is an integer list naming those stories being assigned a maximum relative story deflection by a given entry of this command.

v_1 is the value of the maximum relative story deflection designated by this command. This value must have the units of inches.

Explanation:

This command allows the user to specify the maximum lateral structural stiffness to be designed into the building by specifying a maximum allowable relative story deflection under working loads. An often used factor for maximum elastic relative story deflection is 1/400 X story height.

Possible errors:

Data input via this command is necessary to the PLADS I elastic stiffness design procedures. Command syntax errors or neglect in specifying maximum story deflection data prior to the execution of elastic stiffness design results in an error condition and the following error message being printed and execution terminated.

> ***** ERROR -- MAXIMUM RELATIVE STORY DEFLECTIONS AT WORKING LOADS NOT INPUT PROPERLY. EXECUTION WILL BE TERMINATED. *****

The specification of this data is optional and may be omitted in cases where only the plastic design and approximate analysis procedures are executed.

15. Specification of Maximum Elastic Stresses at Working Loads

General form:

MAXIMUM (PERMISSIBLE) ELASTIC (MEMBER STRESS AT - WORKING LOADS)

$$\text{STORY list}_1 \begin{Bmatrix} \text{BEAMS} \\ \\ \text{COLUMNS} \end{Bmatrix} \text{list}_2 \left[\underline{\text{F}}\right] v_1$$

.
.
.

$\underline{\text{ST}}\text{ORY list}_1 \begin{Bmatrix} \underline{\text{BE}}\text{AMS} \\ \underline{\text{COL}}\text{UMNS} \end{Bmatrix} \text{ list}_2 \ [\underline{\text{F}}] \ v_n$

Individual form:

MAXIMUM (PERMISSIBLE) ELASTIC (MEMBER STRESS AT WORKING LOADS)

$\underline{\text{ST}}\text{ORY list}_1 \begin{Bmatrix} \underline{\text{BE}}\text{AMS} \\ \underline{\text{COL}}\text{UMNS} \end{Bmatrix} \text{ list}_2 \ [\underline{\text{F}}] \ v_1$

Elements:

$list_1$ and $list_2$ are integer lists naming the beams and columns in a story or group of stories whose maximum elastic stress is being specified in a particular command entry.

v_1 is the value of the maximum elastic stress for the elements designated by the lists. This value must have the units of ksi (kips/in^2).

Explanation:

This command allows the engineer user to specify the maximum permissible elastic stress for beams and columns to be used as the elastic stress limits in the elastic stress design procedure for unfactored of service gravity and combination loading conditions (maximum elastic stress for bracing assumed to be specified bracing yield stress). If a maximum stress is not specified, for any member, beam or column, then the default value of the appropriate yield stress is assumed.

It is important to note that for the elastic stiffness design procedure to be valid, the maximum elastic stresses under the service loading conditions must be less than or equal to the yield stress.

Example:

(a) MAXIMUM STRESSES AT WORKING LOADS
STORIES ALL BEAMS ALL F 36.0
STORIES ALL COLUMNS ALL F 36.0

(b) MAXIMUM STRESS STORIES ALL BEAMS ALL F 24.0

Possible errors:

If command syntax errors occur or the specification of maximum stress data for any member is neglected, the following appropriate diagnostic message is printed.

***** NOTE -- YOU HAVE NOT SPECIFIED A MAXIMUM ELASTIC STRESS FOR ALL BEAMS. THE APPROPRIATE YIELD STRESS WILL BE ASSUMED FOR BEAMS WHOSE MAXIMUM ELASTIC STRESS IS NOT SPECIFIED. *****

***** NOTE -- YOU HAVE NOT SPECIFIED A MAXIMUM ELASTIC STRESS FOR ALL COLUMNS. THE APPROPRIATE YIELD STRESS WILL BE ASSUMED FOR COLUMNS WHOSE MAXIMUM ELASTIC STRESS IS NOT SPECIFIED. *****

16. Specification of Member Lateral Support Intervals

General form:

<u>LAT</u>ERAL (<u>SUP</u>PORT <u>INT</u>ERVAL)

$\underline{\text{ST}}\text{ORIES list}_1 \begin{Bmatrix} \underline{\text{BE}}\text{AMS} \\ \underline{\text{COL}}\text{UMNS} \end{Bmatrix} \text{list}_2 \left[\underline{\text{L}}\text{ENGTH}\right] v_1$

.
.
.

$\underline{\text{ST}}\text{ORIES list}_1 \begin{Bmatrix} \underline{\text{BE}}\text{AMS} \\ \underline{\text{COL}}\text{UMNS} \end{Bmatrix} \text{list}_2 \left[\underline{\text{L}}\text{ENGTH}\right] v_n$

Individual form:

$\underline{\text{LAT}}\text{ERAL (}\underline{\text{SUP}}\text{PORT }\underline{\text{INT}}\text{ERVAL) }\underline{\text{ST}}\text{ORIES list}_1 \begin{Bmatrix} \underline{\text{BE}}\text{AMS} \\ \underline{\text{COL}}\text{UMNS} \end{Bmatrix}\text{-}$

$\text{list}_2 \left[\underline{\text{L}}\text{ENGTH}\right] v$

Elements:

$list_1$ and $list_2$ are integer lists naming the beams or columns in a story or group of stories whose lateral support interval is being specified in a particular command entry.

v_1 is the value of the lateral support interval for the elements designated by the lists. This value must have the units of <u>inches</u>.

Explanation:

One of the critical stipulations contingent to the application of plastic design principles, as specified by the 1970 AISC Code (2), is that the compression flanges of beams and columns be adequately braced in the vicinity of the plastic hinges. This stipulation is intended to preclude the formation of local member instabilities prior to the section reaching its plastic moment capacity.

This command allows the engineer user to specify the compression flange lateral support interval for beams and columns for use in design.

Examples:

(a) LATERAL SUPPORT INTERVAL
    STORIES ALL BEAMS ALL L 36.0
    STORIES ALL COLUMNS ALL L 72.0

(b) LATERAL SUPPORT STORIES ALL BEAMS ALL 48.0

Possible errors:

If command syntax errors occur or the specification of this data for any particular element is neglected, the following diagnostic message is printed.

***** NOTE -- YOU HAVE NOT SPECIFIED A MAXIMUM LATERALLY UNSUPPORTED BEAM LENGTH. A LATERALLY UNSUPPORTED LENGTH OF 48.0 INCHES IS ASSUMED FOR BEAMS WHOSE LATERALLY UNSUPPORTED LENGTH IS NOT SPECIFIED. *****

or

***** NOTE -- YOU HAVE NOT SPECIFIED A MAXIMUM LATERALLY UNSUPPORTED COLUMN LENGTH. THE APPROPRIATE STORY HEIGHT WILL BE ASSUMED FOR COLUMNS WHOSE LATERALLY UNSUPPORTED COLUMN LENGTH IS NOT SPECIFIED. *****

As implied by these two messages, the specification of lateral support intervals for beams and columns is optional and these commands may be omitted.

17. Specification of Maximum Member Depth

General form:

MAXIMUM (PERMISSIBLE MEMBER) DEPTH

STORIES $list_1$ $\begin{Bmatrix} \text{BEAMS} \\ \text{COLUMNS} \end{Bmatrix}$ $list_2$ [DEPTH] v_1

.
.
.

STORIES $list_1$ $\begin{Bmatrix} \text{BEAMS} \\ \text{COLUMNS} \end{Bmatrix}$ $list_2$ [DEPTH] v_n

Individual form:

MAXIMUM (PERMISSIBLE MEMBER) DEPTH STORIES -

$list_1$ $\begin{Bmatrix} \text{BEAMS} \\ \text{COLUMNS} \end{Bmatrix}$ $list_2$ [DEPTH] v

Elements:

$list_1$ and $list_2$ are integer lists naming those beams or columns in a story or group of stories being assigned maximum depths by this command.

v_1 is the value of the maximum depth being assigned to those elements named in the lists. These values must have the units of <u>inches</u>.

Explanation:

In certain design cases, the depth of a member may be one of the critical constraints. This command allows the user to specify maximum member depths. When specifying maximum depths for beams and columns, the user must remember that the non-economy beam and column section tables must contain members able to satisfy these specified depth constraints.

This data is optional and the command may be omitted in which case the following messages are printed and refer to all those elements for which a maximum depth was not specified.

***** NOTE -- YOU HAVE NOT SPECIFIED A MAXIMUM PERMISSIBLE BEAM DEPTH FOR ALL BEAMS. A MAXIMUM DEPTH OF 10000.0 INCHES WILL BE ASSUMED FOR BEAMS WHOSE MAXIMUM DEPTH IS NOT SPECIFIED. *****

or

***** NOTE -- YOU HAVE NOT SPECIFIED A MAXIMUM PERMISSIBLE COLUMN DEPTH FOR ALL COLUMNS. A MAXIMUM DEPTH OF 10000.0 INCHES WILL BE ASSUMED FOR COLUMNS WHOSE MAXIMUM DEPTH IS NOT SPECIFIED. *****

Examples:

(a) MAXIMUM MEMBER DEPTH
STORIES 1 TO 10 BEAMS 2 DEPTH 17.0

(b) MAXIMUM PERMISSIBLE DEPTH STORIES 11 TO 15 -
BEAMS 1,3 DEPTH 24.0

Possible errors:

Command syntax errors will result in the above message being printed and the default option used for those structural elements designated by the command in error.

18. Specification of Panel Modes of Resistance of Ultimate Story Shears

General form:

PANEL (RESISTANCE FOR ULTIMATE SHEARS AT ULTIMATE - LOADS)

$$\text{STORIES list}_1 \text{ PANELS list}_2 \left\{\begin{matrix}\text{MOMENT}\\ \text{TRUSS}\\ \text{BOTH}\\ \text{NONE}\end{matrix}\right\}$$

⋮

$$\text{STORIES list}_1 \text{ PANELS list}_2 \left\{\begin{matrix}\text{MOMENT}\\ \text{TRUSS}\\ \text{BOTH}\\ \text{NONE}\end{matrix}\right\}$$

Individual form:

$$\text{PANEL (RESISTANCE MODES FOR ULTIMATE SHEARS AT - ULTIMATE LOADS) STORIES list}_1 \text{ PANELS list}_2 \left\{\begin{matrix}\text{MOMENT}\\ \text{TRUSS}\\ \text{BOTH}\\ \text{NONE}\end{matrix}\right\}$$

Elements:

$list_1$ and $list_2$ are integer lists naming those panels in the story or group of stories having their permissible modes of ultimate shear resistance specified by this command.

MOMENT = resistance of ultimate story shear only by bending action in a given panel.

TRUSS = resistance of ultimate story shear only by truss (axial) action of a tension brace and beams and columns in a given panel.

BOTH = resistance of ultimate story shear by a combination of both moment and truss action.

NONE = no resistance to ultimate story shear is to be provided by the particular panels named.

Explanation:

As summarized in CHAPTER II, plastic design in PLADS I employs a story-by-story iterative method by which, during each iteration on each story, the total story shear, including P-delta effects, is incrementally distributed into the individual panels of the story under consideration. A panel is chosen to carry an increment of total story shear based on the minimum increase in cost of the members in the structure due to the application of an incremental shear to the story panel.

This command, then, allows the user to specify the manner in which members in the panels of each story will resist the increments of story shear applied during a plastic design execution. If the user specifies moment resistance for a particular panel, that panel may only provide bending resistance to any added story shear. The truss specification means that a tension X-bracing system is acting in that panel and any increment of story shear applied to the panel is resisted only by axial forces in the beams, columns, and tension brace in the panel. The specification of both truss and moment shear resistance for a panel provides the user with a very powerful plastic design capability. If this condition is specified for a particular panel, PLADS I, during the plastic design process, will choose the mode of resistance, either moment or truss, which minimizes the cost increase of the panel due to its increased capacity to resist an increment of ultimate story shear. The specification of NONE implies that no increment of story shear will be applied to that particular panel during the design process.

The engineer user should consider the following implications when specifying panel modes of resistance. In plastic design methods currently employed, it is assumed that all story shear, in a braced frame, is carried by the braced panels. In moment resisting frames, of course, all story shear is resisted in the bending mode. However, in PLADS I plastic design, the structure under design may be provided with the capability of resisting story shear in a truss mode for braced panels, and a bending mode for unbraced panels.

Examples:

(a) PANEL SHEAR RESISTANCE

STORIES ALL PANEL 4 TRUSS

STORIES ALL PANELS 1 TO 3 NONE

This examples forces the frame to resist lateral loads as a braced frame with bracing elements permitted in panel 4 only.

(b) PANEL RESISTANCE STORIES ALL PANELS ALL BOTH

This example allows PLADS I to distribute factored lateral forces in such a way as to minimize (in heuristic sense) member size increases above that required for factored gravity load design.

Possible errors:

This is the most important command to the PLADS I plastic design procedure. A mode of story resistance must be specified for every panel in a structure to be designed. Failure to do this, or the occurance of a command syntax error will result in the termination of the problem with the following error message printed.

***** ERROR -- COMPLETE PANEL ACTION FOR THE FRAME NOT SPECIFIED CORRECTLY. EXECUTION WILL BE TERMINATED. *****

19. Specification of Weak Beam - Strong Column Design Constraint

General form:

<u>WE</u>AK (<u>B</u>EAM <u>S</u>TRONG <u>C</u>OLUMN) $\begin{Bmatrix} \underline{\text{YES}} \\ \underline{\text{NO}} \end{Bmatrix}$

Explanation:

In the case of plastic design of tall structures where stability is a particularly important consideration, it is usually recommended that reasonable assurance be provided that plastic hinges occur in beams before they occur in columns. This command provides the user with the capability of invoking a design check routine at the completion of each plastic design cycle. The YES option invokes the routine which increases column sizes framing into a particular joint as a check, described in CHAPTER II, shows that the sum of the reduced plastic moment capacities of the beams framing into the joint exceeds the sum of the reduced plastic moment capacities of the columns framing into the joint, until the weak beam - strong column constraint is satisfied. This command is optional, and if neglected or omitted, PLADS I assumes that the constraint is not to be satisfied. This is also the case if a command syntax error occurs.

20. Effective Length Computation for Column Design in Plastic Design

General form:

EFFECTIVE (LENGTH COMPUTATION FOR COLUMN DESIGN) -

$\left\{ \begin{array}{l} \underline{\text{YES}} \\ \underline{\text{NO}} \end{array} \right\}$

Explanation:

PLADS I allows plastic design of unbraced frames of any number of stories. This command allows the user to automatically include the computation of column effective lengths or K factors according to the specifications of the American Institute of Steel Construction (2). If specified YES, this K factor computation for columns is included under the following design conditions:

(1) In gravity load only plastic design (which is executed once to obtain a minimum member property configuration) <u>if for a given story no bracing whatsoever is permitted</u>.

(2) In the combination load design for a completely unbraced story.

The K factor computation is ignored if NO is specified of the issue of this command is neglected or a syntax error is discovered during the interpretation of this command.

<u>Design and Analysis Directives</u>. This section describes the commands which provide the user with the capability of controlling the design and analysis processes. These commands allow the user to request either a complete system design which includes plastic and elastic stiffness and stress design, or elastic stiffness and stress designs only, or plastic design only, or elastic stiffness analysis only. Also included in this section is a command to allow consideration of column axial deformation in the computation of delta for the P-delta effect.

1. Design Directives

General form:

$$\underline{\text{DES}}\text{IGN} \begin{Bmatrix} \underline{\text{SYS}}\text{TEM} \\ \underline{\text{P}}\text{LASTIC} \\ \underline{\text{E}}\text{LASTIC} \end{Bmatrix} \quad \begin{Bmatrix} \underline{\text{NUM}}\text{BER (}\underline{\text{OF}}\ \underline{\text{C}}\text{YCLES)} & i \\ \text{(}\underline{\text{TO}}\text{) }\underline{\text{CON}}\text{VERGENCE} & \end{Bmatrix}$$

Elements:

i is the maximum number of cycles of SYSTEM, PLASTIC or ELASTIC design to be executed. This may be any number greater than or equal to one.

CONVERGENCE specifies that the particular design procedure specified will execute until convergence to a satisfactory design. However, due to considerations of economy, a limit of 50 design iterations is set within the system when CONVERGENCE is specified.

Explanation:

At the present time, PLADS I provides the user with separate design alternatives and combinations thereof. Specification of SYSTEM design will invoke complete plastic design followed by an elastic stiffness design based on user specified relative story deflection limits, and an elastic stress design based on user specified stress limits. Specification of PLASTIC design will invoke a plastic design only to convergence or up to the number of iterations specified. Specification of ELASTIC design will invoke only elastic stiffness and elastic stress design to convergence or up to the number of cycles specified. Note that an initial member property configuration must be specified prior to the issue of a DESIGN ELASTIC command if at least one cycle of plastic design was not previously completed.

Examples:

(a) DESIGN SYSTEM TO CONVERGENCE

This command requests a complete system design (plastic, elastic and stiffness) until convergence.

(b) DESIGN PLASTIC NUMBER OF CYCLES 1
DESIGN ELASTIC TO CONVERGENCE

In this example, the user has requested one cycle of plastic design to obtain a quick estimation of member sizes after which a complete elastic design is invoked. In this combination of design requests, a user specified member property configuration is not needed.

(c) DESIGN ELASTIC NUMBER OF CYCLES 3

This command requests a maximum of three cycles of elastic design. In this case, when plastic design is not first requested, an initial member property configuration must be input by the user.

Possible errors:

Command syntax errors or neglecting the specification of these design commands will result in no design execution. Command syntax errors will result in the following message being printed.

***** ERROR -- ERROR IN DESIGN DIRECTIVE COMMAND.
SCANNING MODE IS ENTERED. *****

Also, prior to the execution of any design procedure, a complete input data check is made and if any errors are detected, execution is aborted and the appropriate error message, as described in the above command listings, is printed.

2. Analysis Directives

General form:

ANALYSIS ELASTIC (STIFFNESS)

Explanation:

Besides the design procedures described above, PLADS I also provides an independent rectangular frame analysis procedure. The stiffness analysis command invokes an exact matrix stiffness analysis of the braced and unbraced frames being considered under the action of both the unfactored gravity load condition and the unfactored gravity plus lateral load condition. The complete elastic stiffness analysis of a frame is executed in three phases for which joint displacement and member force results are generated. These three phases are: (1) gravity loading only acting on the unbraced frame; (2) two separate analyses for the gravity loading acting on the frame with a tension bracing configuration for wind from the left and wind from the right respectively; and (3) two separate analyses for the lateral loads, acting from both the left and right respectively, on the frame with tension bracing for wind from the left and wind from the right appropriately.

Examples:

(a) ANALYSIS ELASTIC STIFFNESS

The use of this command alone invokes a stiffness analysis of a structure whose member property configuration has previously been specified by the user with the MEMBER PROPERTY command.

(b) PLASTIC DESIGN TO CONVERGENCE
ANALYSIS STIFFNESS

This combination of commands allows the user to gain some insight into the elastic behavior of the braced and unbraced frame with a member property configuration resulting from a complete plastic design.

Possible errors:

Command syntax errors will result in problem termination. Prior to the execution of these two analysis procedures, a complete check of required input data is made and if any errors are detected, execution is aborted and the appropriate error messages are printed.

3. Command for the Inclusion of Column Elongation and Shortening Effects in the Computation of delta for the P-delta effect

General form:

PDELTA (COMPUTATION FOR COLUMN ELONGATION AND -

SHORTENING EFFECTS) $\left\{\begin{matrix}\underline{\text{YES}}\\ \underline{\text{NO}}\end{matrix}\right\}$

Explanation:

CHAPTER II describes how column axial deformation effects may be included in the computation of delta for the P-delta design process. This command simply allows these effects to be included or ignored depending on the engineering judgement of the user.

The YES option specifies that the column axial deformation effects should be considered while the NO option specifies that these effects should be ignored. If this command is not issued, it is automatically assumed that column axial deformations will not be computed for delta in the P-delta effect.

Commands to Control Output. At the present time, PLADS I does not contain the capabilities of extensive output control. PLADS I commands are currently available to control the amount of design and analysis output and request the listing of input data.

1. Printing of Input Data

General form:

PRINT PROBLEM (INPUT DATA)

Explanation:

This command is used to request a listing of all input data specified to PLADS I up to the issue of this command. The print command may be issued at anytime, but a good method to follow is to run a job with no design or analysis execution, but using the PRINT and SAVE commands following the data input. This procedure will assure the user that all of his input is correct prior to requesting a more time consuming analysis or design at a later time using PLADS RESTORE.

2. Control of Output of Results

General form:

$$\underline{\text{OUT}}\text{PUT}\quad\left\{\begin{array}{l}\underline{\text{DEB}}\text{UGGING (}\underline{\text{DA}}\text{TA)}\\ \underline{\text{INTER}}\text{MEDIATE (}\underline{\text{DE}}\text{SIGN }\underline{\text{A}}\text{ND }\underline{\text{A}}\text{NALYSIS }\underline{\text{D}}\text{ATA)}\\ \underline{\text{FINAL}}\text{ (}\underline{\text{DE}}\text{SIGN }\underline{\text{A}}\text{ND }\underline{\text{A}}\text{NALYSIS }\underline{\text{D}}\text{ATA)}\\ \underline{\text{PDELTA}}\text{ (}\underline{\text{CON}}\text{VERGENCE }\underline{\text{IN}}\text{FORMATION)}\end{array}\right\}$$

Explanation:

This command provides the user with the capability of controlling the amount of output he is to receive. It must be given prior to design or analysis directive commands. With the request for debugging data the user should expect extensive output of code parameter values and array elements as well as intermediate and final design results. This information is only of use to PLADS I system developers. If debugging data is not explicitly requested, it is not provided. With the request for intermediate design and analysis data the user should expect the results of the latest plastic or elastic design cycle, as well as final results. The request for final design and analysis data allows only the output of design results following the completion of a plastic or elastic design procedure. A request for P-delta convergence information allows the printing, at the end of each plastic design cycle, of the current values of the relative story deflections which can be used to determine convergence characteristics of the plastic design iteration.

The following is an explanation of design and analysis results printed out by PLADS I.

Plastic design results:

(1) Final member property configuration or, if requested, the intermediate member property configuration following each plastic design cycle. These data consist of beam, column and bracing sections including section name and corresponding section table number for both the gravity and the gravity plus lateral load conditions.

(2) Final story panel shear distribution or, if requested, the intermediate story panel shear distribution following each plastic design cycle. For each story, the total story shear capacity, including P-delta effects is output, followed by the distribution of this shear throughout the panels of each story for lateral forces from the left and right.

(3) Total material cost and weight after the complete plastic design or, if requested, after each plastic design cycle.

(4) Output of required design moment and axial force diagrams for beams and columns for the factored gravity and factored gravity plus lateral load conditions. For each beam, the axial force - assumed equal to 0.00 for the factored gravity load condition - and left end, right end, and center moments are output. For each column, the axial force, including live load reduction, and the top and bottom moments are output. Note that output of top and bottom column moments and right and left beam end moments due to the factored gravity and factored gravity plus lateral loading conditions are at the joint centers.

(5) Output of the required design axial force diagram for bracing for the factored gravity plus lateral load condition.

(6) Output of the required reduced plastic moment capacities in the presence of axial force for beams and columns. This reduced plastic moment capacity is the maximum moment a member can experience in the presence of axial force. Note that this moment value is used in the AISC interaction equations 2.4-2 and 2.4-3 for the applied moment value M. It is equal to the maximum beam or column moment from among the gravity and gravity plus lateral load conditions, considering the moments at the beam center and beam ends at the column flange location (this accounts for joint size effect), and at the

column ends at the beam flange location. However, the actual axial force is used in these equations when checking the two loading conditions. This is conservative.

(7) Output of final relative story deflections at collapse.

(8) Output of column effective length factors for complete plastic design. Beam effective length factors are always assumed equal to 1.00.

(9) Output of values for AISC interaction equation 2.4-3 for beams and equations 2.4-2 and 2.4-3 for columns following complete plastic design.

Elastic design:

(1) Output of final horizontal, vertical and rotational joint displacements for working (unfactored) gravity loads only acting on the unbraced frame, working gravity loads only acting on the frame braced with tension bracing for lateral loads from the left, working gravity loads only acting on the frame braced with tension braces for lateral loads from the right only, working lateral loads from the left only acting on the frame braced with tension braces for such loads, and working lateral loads from the right only acting on the frame braced with tension braces for such loads. If requested, this output is also generated at the end of each complete elastic stiffness and stress design cycle.

(2) Output of member forces and reactions for

working gravity loads only, and working gravity plus lateral loads from the left and right. If requested, this output is also generated at the start of each elastic stress and stiffness design cycle.

(3) Output of final maximum elastic member stresses. If requested, this output is generated before and after each intermediate elastic stress design.

(4) Final total material weight and cost after the stress design part and stiffness design part of elastic design. If requested, this data is output for these two design phases in each intermediate elastic design cycle.

(5) Output of final member property configuration including section name and corresponding section table number for both the elastic stress and elastic stiffness design phases of elastic design. Again, if requested, this data is output in each intermediate elastic design cycle.

(6) Output of final member property configuration and corresponding section table numbers at the start and end of the final plastic design check after elastic design.

(8) Output of final column effective length factors for final plastic design check after elastic design. Here again, beam effective length factors are assumed equal to 1.00.

(9) Output of values of AISC interaction equation 2.4-3 for beams and equations 2.4-2 and 2.4-3 for columns in the final plastic design check after elastic design.

It should be noted that the OUTPUT command itself does not generate plastic and elastic design and analysis output. The design and analysis programs generate this output while the OUTPUT command simply sets flags within these design and analysis programs which control the amount of this output to be printed out. Any series of OUTPUT commands may be issued in any sequence. For example:

```
OUTPUT FINAL
OUTPUT PDELTA.
```

CHAPTER IV

SUMMARY OF RESULTS

Introduction

This chapter is devoted to the presentation of example problems demonstrating the application of ICES PLADS I. The problems presented are divided into three different problem sets.

Problem Set 1 presents the results of five 24-story, 3 bay frame (basically Lehigh Frame C (12)) total designs which include a complete plastic design followed by complete elastic stress and stiffness designs. These results are intended to demonstrate the validity of the design processes by showing the effects of a series of different ultimate shear resistance patterns on the design results of ICES PLADS I.

Problem Set 2 presents results in order to demonstrate the effects of additional design constraints on the design of selected examples of Problem Set 1. The additional design constraints used are: the specification of ASTM A441 (50 ksi.) steel in some columns; depth constraints for beams; the weak beam - strong column design constraint; and the inclusion of column axial deformations in the P-delta effect.

The problems in Problem Sets 1 and 2 are constructed very similarly to the example problems presented in Chapter 2 of Emkin's Thesis (5) so that if comparisons are made, the differences noted will be due to the changes described in CHAPTER II of this report. In the interest of providing results which depict a more realistic design situation, an additional example problem is considered in Problem Set 2 wherein columns have lateral support against out-of-plane bending at their ends only, rather than at 6 ft. intervals as in the other examples.

Finally, Problem Set 3 consists of the designs of two 6 story, 3 bay unbraced frames, the results of which are intended to show the effects of column effective length factors on column design.

Input Data for Problem Set 1

Problem Set 1 consists of the following five example problems. It is important to remember that in PLADS I, a given panel may resist lateral story shear by either moment or truss action. In the first four of the following problems, lateral story shear may be resisted by panel moment action in addition to panel truss action in the bays indicated. The fifth problem permits lateral story shear to be resisted only by panel truss action.

1. Example Problem C1.1A: 24 story, 3 bay frame; A36 (36 ksi) steel; bracing permitted in bay 3 only;

total plastic design (10 per cent P-delta convergence) followed by total elastic stress and stiffness designs (Fig. 8)

2. Example Problem C2.1A: 24 story, 3 bay frame; A36 steel; bracing permitted in any bay; total plastic design (10 per cent P-delta convergence) followed by total elastic stress and stiffness designs (Fig. 9).

3. Example Problem C3.1A: 24 story, 3 bay frame; A36 steel; bracing permitted in bay 1 only; total plastic design (10 per cent P-delta convergence) followed by total elastic stress and elastic stiffness designs (Fig. 10).

4. Example Problem C4.1A: 24 story, 3 bay frame; A36 steel; bracing permitted in bay 2 only; total plastic design (10 per cent P-delta convergence) followed by total elastic stress and elastic stiffness designs (Fig. 11).

5. Example Problem C5.1A: 24 story, 3 bay frame; A36 steel; bracing permitted in bay 3 only; lateral shear resistance by truss action in bay 3 only; no resistance to lateral shear by moment action permitted in any bay; total plastic design (10 per cent P-delta convergence) followed by total elastic stress and stiffness designs (Fig. 12).

The following is a listing of the ICES PLADS I commands necessary for data input to the above five problems.

```
PLADS
$     GEOMETRIC DATA
      NUMBER OF STORIES  24
      NUMBER OF BAYS  3
      STORY HEIGHTS ALL  144.0
      BAY LENGTHS
           1 LENGTH  240.0
           2 LENGTH  144.0
           3 LENGTH  336.0
$     SECTION PROPERTY TABLE DATA
      SECTION BEAM ECONOMY  38
      SECTIONS BEAM TOTAL NUMBER  87
      (total beam section table, see APPENDIX I)
      SECTIONS COLUMN ECONOMY  48
      SECTIONS COLUMN TOTAL NUMBER  48
      (total column section table, see APPENDIX I)
      SECTIONS BRACING  26
      (total bracing section table, see APPENDIX I)
$     LOADING CONDITION DATA
      LOAD FACTORS DEAD PLUS LIVE  1.7-
      DEAD PLUS LIVE PLUS WIND  1.3
      LOADING LATERAL STORY 1  Q  4.8
      LOADING LATERAL STORIES 2 TO 24  Q  5.76
      LOADING UNIFORM
           STORY 1 BEAMS ALL DL 0.19 LL 0.06
           STORIES 2 TO 24 BEAM 1 DL 0.24 -
           LL 0.123333
           STORIES 2 TO 24 BEAM 2 DL 0.24 LL -
           0.154167
           STORIES 2 TO 24 BEAM 3 DL 0.24 LL -
           0.098333
      LOADING CONCENTRATED
           STORY 1 JOINTS 1,4 DL 15.7 LL 0.0
           STORY 1 JOINTS 2,3 DL 7.5 LL 0.00
           STORIES 2 TO 24 JOINTS 1,4 DL 32.0 -
           LL 0.0
           STORIES 2 TO 24 JOINTS 2,3 DL 7.5 LL 0.0
      LIVE LOAD REDUCTION FACTORS
           STORY 1 COLUMNS ALL 0.00
           STORY 2 COLUMN 1 0.192
           STORY 2 COLUMN 2 0.307
           STORY 2 COLUMN 3 0.384
           STORY 2 COLUMN 4 0.269
           STORY 3 COLUMN 1 0.384
           STORY 3 COLUMNS 2,3,4 0.509
           STORIES 4 TO 24 COLUMNS ALL 0.509
$     MEMBER DESIGN DATA
           YIELD STRESS STORIES ALL BEAMS ALL-
      FY 36.0
           YIELD STRESS STORIES ALL COLUMNS ALL-
      FY 36.0
```

```
          YIELD STRESS STORIES ALL BAY BRACING -
          ALL FY 36.0
     MATERIAL UNIT PRICES
          STORIES ALL BEAMS ALL COST 20.0
          STORIES ALL COLUMNS ALL COST 20.0
          STORIES ALL BAY BRACING ALL COST 20.0
$    DESIGN CONSTRAINTS
          PANEL SHEAR RESISTANCE
          (This command is different for each
example problem.  See listing below.)
          LATERAL SUPPORT INTERVALS
               STORIES ALL BEAMS ALL LENGTH 36.0
               STORIES ALL COLUMNS ALL LENGTH 72.0
          ASSUMED INITIAL RELATIVE DEFLECTION AT -
          ULTIMATE LOAD
               STORIES ALL DELTA 0.39
          MAXIMUM PERMISSIBLE RELATIVE DEFLECTION -
          AT WORKING LOADS
               STORIES ALL DELTA 0.36 $ STORY -
               HEIGHT/400.0
          MAXIMUM PERMISSIBLE ELASTIC STRESS AT -
          WORKING LOADS
               STORIES ALL BEAMS ALL F 36.0
               STORIES ALL COLUMNS ALL F 36.0
               $ MAXIMUM ELASTIC STRESS FOR -
               BRACING ASSUMED EQUAL TO YIELD -
               STRESS
          TOLERANCE FOR PDELTA CONVERGENCE 0.10 -
          $ 10%
          EFFECTIVE LENGTH COMPUTATION FOR COLUMN -
          DESIGN NO
          WEAK BEAM STRONG COLUMN DESIGN CON -
          STRAINT NO
$    DESIGN AND OUTPUT COMMANDS
          OUTPUT FINAL DESIGN AND ANALYSIS DATA
          PDELTA COMPUTATION FOR COLUMN ELONGATION -
          AND SHORTENING NO
          DESIGN PLASTIC TO CONVERGENCE
          DESIGN ELASTIC TO CONVERGENCE
          FINISH
```

As noted above, the following listings are the commands for each problem which tabulate the panel shear resistance data:

```
$ PANEL SHEAR RESISTANCE MODES - EX. C1.1A
     STORIES ALL PANEL 3 BOTH MOMENT AND TRUSS
     STORIES ALL PANELS 1,2 MOMENT
```

```
$ PANEL SHEAR RESISTANCE MODES - EX. C2.1A
    STORIES ALL PANELS ALL BOTH MOMENT AND TRUSS

$ PANEL SHEAR RESISTANCE MODES - EX. C2.1A
    STORIES ALL PANEL 1 BOTH MOMENT AND TRUSS
    STORIES ALL PANELS 2,3 MOMENT

$ PANEL SHEAR RESISTANCE MODES - EX. C4.1A
    STORIES ALL PANEL 2 BOTH MOMENT AND TRUSS
    STORIES ALL PANELS 1,3 MOMENT

$ PANEL SHEAR RESISTANCE MODES - EX. C5.1A
    STORIES ALL PANEL 3 TRUSS
    STORIES ALL PANELS 1,2 NONE
```

Input Data for Problem Set 2

Problem Set 2 consists of the following five example problems. The five problems are exactly the same as Example Problem C1.1A except that certain additional design constraints are imposed for each problem as follows.

1. Example Problem C6.1A: ASTM A36 steel in all columns of stories 13 to 24 is changed to ASTM A441 steel at 50 ksi yield stress, total design (Fig. 13).

2. Example Problem C7.1A: Example Problem C1.1A except that beam depth constraints of 17 inches for all beams of stories 1 to 12 and 20 inches for all beams of stories 13 to 24 are imposed; total design (Fig. 14).

3. Example Problem C8.1A: Example Proble C1.1A except that the weak beam - strong column design constraint is imposed; plastic design only (Fig. 15).

4. Example Problem C9.1A: Example Problem C1.1A except that column axial deformations are included in

the P-delta effect; plastic design only (Fig. 16).

5. Example Problem C10.1A: Example problem C1.1A except that laterally unbraced column lengths are set to the <u>full</u> story height (Fig. 17).

The following listing presents the ICES PLADS I command changes necessary to Example Problem C1.1A in order to execute the above five example problems.

For Example Problem C6.1A, the command specifying column yield stress is changed to:

```
YIELD STRESS STORIES 1 TO 12 COLUMNS ALL FY 36.0
YIELD STRESS STORIES 13 TO 24 COLUMNS ALL FY 50.0
```

Correspondingly, material cost specification commands for columns must be changed to:

```
STORIES 1 TO 12 COLUMNS ALL COST 20.0
STORIES 13 TO 24 COLUMNS ALL COST 24.0
```

For Example Problem C7.1A add the following commands to the $ DESIGN CONSTRAINTS command group.

```
MAXIMUM MEMBER DEPTHS
     STORIES 1 TO 12 BEAMS ALL DEPTH 17.0
     STORIES 13 TO 24 BEAMS ALL DEPTH 20.0
```

For Example Problem C8.1A the command WEAK BEAM STRONG COLUMN DESIGN CONSTRAINT NO in the $ DESIGN CONSTRAINTS command group is changed to the following:

```
WEAK BEAM STRONG COLUMN DESIGN CONSTRAINT YES
```

For Example Problem C9.1A the command PDELTA COMPUTATION FOR COLUMN ELONGATION AND SHORTENING NO in the $ DESIGN CONSTRAINTS command group is changed to:

```
PDELTA COMPUTATION FOR COLUMN ELONGATION AND -
```

SHORTENING YES

Finally, for Example Problem C10.1A, the command LATERAL SUPPORT INTERVALS STORIES ALL COLUMNS ALL LENGTH 72.0 is deleted, allowing PLADS I to assign column lateral support intervals of 144.0 inches or the full story height by default.

Input Data for Problem Set 3

Problem Set 3 consists of the following two example problems.

1. Example Problem EX1: 6 story, 3 bay unbraced frame; A36 steel; effective lengths of columns computed and used during plastic design; complete plastic design only (Fig. 18).

2. Example Problem EX2: 6 story, 3 bay unbraced frame; A36 steel; all column effective length factors equal to 1.00; complete elastic stress design (Fig. 18).

The following is the ICES PLADS I command listing for Example Problem EX1.

```
PLADS
$    GEOMETRIC DATA
          NUMBER OF STORIES 6
          NUMBER OF BAYS 3
          STORY HEIGHTS ALL 144.0
          BAY 1 LENGTH 240.0
          BAY 2 LENGTH 144.0
          BAY 3 LENGTH 336.0
$    SECTION PROPERTY TABLE DATA
          SECTIONS BEAM ECONOMY 38
          SECTIONS BEAM TOTAL NUMBER 87
          (total beam section table)
          SECTIONS COLUMN ECONOMY 48
          SECTIONS COLUMN TOTAL NUMBER 48
```

```
     (total column section table)
     SECTIONS BRACING TOTAL NUMBER 26
     (total bracing section table)
$    LOADING CONDITION DATA
          LOAD FACTORS F1 1.70 F2 1.3
          LOADING LATERAL STORY 1 Q 4.8
          LOADING LATERAL STORIES 2 TO 6 Q 5.76
          LOADING UNIFORM STORY 1 BEAMS ALL DL -
          0.19 LL 0.06
          LOADING UNIFORM STORIES 2 TO 6 BEAM 1 -
          DL 0.24 LL 0.123333
          LOADING UNIFORM STORIES 2 TO 6 BEAM 2 -
          DL 0.24 LL 0.154167
          LOADING CONCENTRATED
               STORY 1 JOINTS 1,4 DL 15.7 LL 0.00
               STORY 1 JOINTS 2,3 DL 7.5 LL 0.00
               STORIES 2 TO 6 JOINTS 1,4 DL 32.0 -
               LL 0.00
               STORIES 2 TO 6 JOINTS 2,3 DL 7.5 -
               LL 0.00
          LIVE LOAD REDUCTION FACTORS
               STORY 1 COLUMNS ALL 0.00
               STORY 2 COLUMN 1 0.192
               STORY 2 COLUMN 2 0.307
               STORY 2 COLUMN 3 0.384
               STORY 2 COLUMN 4 0.269
               STORY 3 COLUMN 1 0.384
               STORY 3 COLUMNS 2,3,4 0.509
               STORIES 4,5,6 COLUMNS ALL 0.509
$    MEMBER DESIGN DATA
          YIELD STRESS STORIES ALL BEAMS ALL FY -
          36.0
          YIELD STRESS STORIES ALL COLUMNS ALL -
          FY 36.0
          YIELD STRESS STORIES ALL BAY BRACING -
          ALL FY 36.0
          MATERIAL UNIT PRICES
               STORIES ALL BEAMS ALL COST 20.0
               STORIES ALL COLUMNS ALL COST 20.0
               STORIES ALL BAY BRACING ALL COST -
               20.0
$    DESIGN CONSTRAINTS
          PANEL SHEAR RESISTANCE STORIES ALL -
          PANELS ALL MOMENT
          LATERAL SUPPORT INTERVALS
               STORIES ALL BEAMS ALL 36.0
          ASSUMED INITIAL RELATIVE DEFLECTION -
          AT ULTIMATE LOAD
               STORIES 1,2,3 DELTA 0.50
               STORIES 4,5,6 DELTA 1.00
          PDELTA COMPUTATION FOR COLUMN ELONGATION -
```

```
AND SHORTENING NO
EFFECTIVE LENGTH COMPUTATION FOR COLUMN -
DESIGN YES
TOLERANCE FOR PDELTA CONVERGENCE 0.10
$ DESIGN DIRECTIVES
OUTPUT FINAL DESIGN AND ANALYSIS DATA
DESIGN PLASTIC TO CONVERGENCE
FINISH
```

The PLADS I command listing for Example Problem EX2 may be generated from Example Problem EX1 by making the following changes.

To the $ DESIGN CONSTRAINT section change the command EFFECTIVE LENGTH COMPUTATION FOR COLUMN DESIGN YES to EFFECTIVE LENGTH COMPUTATION FOR COLUMN DESIGN NO. In addition, add the following commands:

```
MAXIMUM PERMISSIBLE ELASTIC STRESS AT WORKING -
LOADS
     STORIES ALL BEAMS ALL F 36.0
     STORIES ALL COLUMNS ALL F 36.0
     STORIES ALL BAY BRACING ALL F 36.0

MAXIMUM PERMISSIBLE RELATIVE DEFLECTION AT -
WORKING LOADS
     STORIES ALL DELTA 100.0 $ High value for delta
     allows elastic stiffness design to be by-
     passed.
```

In the $ DESIGN DIRECTIVE section, delete

DESIGN PLASTIC TO CONVERGENCE and

OUTPUT FINAL DESIGN AND ANALYSIS DATA

and add the following commands:

OUTPUT INTERMEDIATE DESIGN AND ANALYSIS DATA

DESIGN ELASTIC TO CONVERGENCE

Now, note that elastic design will be invoked without first generating a required member property configuration in plastic design; therefore, to the $ - MEMBER DESIGN DATA command section it is necessary to add the following command:

```
MEMBER PROPERTIES
     STORIES ALL BEAMS ALL TABLE 2
     STORIES ALL COLUMNS ALL TABLE 1
```

where the integers 2 and 1 refer to the second and first members in the beam and column section tables respectively.

Discussion of Results

This section presents a discussion of results illustrating the behavior and practicality of ICES PLADS I. Tables 2 through 5 and Figures 7 through 18 summerize the results for all example problems.

Summery of Results - Problem Set 1

The results of Problem Set 1 demonstrate the validity of the ICES PLADS I design optimization method with respect to how a choice of ultimate story shear resistance pattern affects the total weight of the design solution. This behavior is one of the most basic charactistics and certainly the most important of the PLADS plastic design process. As reviewed in Reference 2, the plastic design optimization procedure is heuristic in nature generating a force distribution which satisfies equilibrium and which tends towards a least weight member property configuration for which there is no guarentee of either a local or global optimality. The generation of this equilibrium force distribution, including P-delta effects, and ultimately, the final plastic design solution is based almost entirely on the choice of the pattern of ultimate story shear resistance; that is, the allowable locations for panel bracing and whether or not unbraced panels may resist story shear by moment action. It is expected that the results of Problem Set 1, presented here, will provide the user of PLADS I with a feeling for the behavior of the plastic design process in view of the points just discussed.

The results of Problem Set 1 are generated for a 24 story, 3 bay frame which is basically the noted Lehigh Frame C with all A36 steel. The results of these five problems are illustrated in Figures 8 through 12. When only plastic design is considered, example C1.1A, bracing allowed in bay 3 only, is only 1.56 per cent lighter than the next heavier example in the problem set (C2.1A; bracing permitted anywhere), and 8.9 per cent lighter than the heaviest example (C4.1A; bracing permitted in bay 2 only). The variation in total plastic design weights of all Problem Set 1 examples seem to be controlled to a large degree by the difference in column and brace weights. Comparing Figures 8, 10 and 12, illustrating the results of example problems C1.1A, C3.1A, and C4.1A respectively, to Figure 7, illustrating the minimum member property configuration for all example problems in Problem Set 1 due to the factored gravity load condition, it is seen that the major column weight variations in these three example problems are due to major column size changes in the columns of the braced bays. Furthermore, in these three comparative examples, the magnitude of the total column design weights varies roughly in an inversely proportional relationship to the length of the braced bay. The plastic design of the frame in example problem C1.1A includes bracing in bay 3, the longest bay, of stories 2 through 24 with a total column weight of 102.35 tons. The next longest bay is bay 1. The design results for example problem C3.1A show that bracing only is designed in bay 1 of stories 2 through 24 resulting in a total column weight of 108.89 tons, and 6 per cent increase over the column weight of example problem C1.1A with the columns of bay 1 demonstrating substantial size increase over the minimum sizes. And finally, example problem C4.1A allows bracing to be designed in bay 2, the shortest of the three bays, of stories 2 through 24 resulting in a total column weight of 115.52 tons, an 11.35 per cent increase over the column weight of example problem C1.1A and a 5.75 per cent increase over the column weight of example problem C3.1A.

This behavior is not surprising because the plastic design optimization method, described in detail in Reference 2, is designed so that in a braced story, the major portion of a given story's ultimate shear capacity is provided by the braced panels. In view of this fact, it is easy to understand this particular design behavior. In the braced panels of a story, the major portion of the ultimate shear is resisted by bracing truss action; thus, as the bay lengths shorten, the vertical component of the bracing force increases and since the satisfaction of the equilibrium condition necessitates that the columns in the braced bays must carry this force, it is necessary that they be designed to accomplish this.

Other interesting points regarding the design behavior of PLADS I with respect to ultimate panel shear resistance patterns is revealed in example C2.1A, the free bracing case. It is conceivable that if a minimum weight design solution for this frame example exists, this solution would be generated by allowing the plastic design processes to select a panel ultimate shear resistance pattern in an unrestricted manner which is the case in example C2.1A where both truss and moment action are permitted in all bays of all stories. However, the results in Table 2 indicate that example C2.1A is 1.55 per cent heavier than the lightest example, C1.1A, due to beam and column weight increases compensated somewhat by a bracing weight decrease, and what appears to be a discrepancy here, in fact demonstrates that a global or local optimum design solution cannot be guaranteed. Indeed, by restricting bracing to bay 3 only, a slightly lighter design solution was generated.

Note that the bracing pattern (Fig. 9) generated for the example C2.1A design solution is very unreasonable which leads one to conclude that some control over the placement of bracing should be exercised.

Another interesting comparison can be made from the results of example problem C1.1A and C5.1A. Example problem C5.1A is the case in which no moment action is permitted in bays 1, 2 and 3 with only a vertical cantilever truss in bay 3 used to resist lateral forces. In this case, example C5.1A is 4.7 per cent heavier than example C1.1A, where the increased weight is due to larger beams, columns and bracing elements in the bay 3 truss system. This result is predictable since no additional lateral force resistance is supplied by moment action in bays 1 and 2 as is the case in example C1.1A.

Summary of Results - Problem Set 2

The results of Problem Set 2 are intended to demonstrate the behavior of the ICES PLADS I subsystem with respect to the imposition of additional design constraints on the design solution of example problem C1.1A. These additional design constraints are repeated here and are: (1) A441, 50 ksi steel specified for columns in stories

13 through 24 - example problem C6.1A; (2) beam depth constraints of 17 in. for beams in stories 1 through 12 and 20 in. for beams in stories 13 through 24 - example problem C7.1A; (3) the weak beam - strong column constraint - example problem C8.1A; (4) inclusion of column axial deformation effects in the plastic design P-delta effect - example problem C9.1A; and (5) columns braced against out of plane bending only at end joints and with a plastic design convergence tolerance of 5 per cent - example problem C10.1A. Table 3 and Figures 13 through 17 summarize the results for these five example problems.

A comparison of Figures 8 and 13 and Tables 2 and 3 for example problems C1.1A and C6.1A reveal a significant 14.3 per cent reduction in the weight of C6.1A over that of C1.1A. This is due almost entirely to the reduced column sizes necessary to satisfy the design constraints in problem C6.1A. This striking reduction in size of these columns is because their higher 50 ksi yield stress makes it possible for much smaller column sizes to satisfy the AISC plastic design equations.

Referring to Figures 8 and 14, illustrating the results of example problems C1.1A and C7.1A respectively, reveals that the beam depth constraints affect only the beams in bay 3 resulting in a beam weight increase of approximately 14.8 per cent from 28.33 tons in problem C1.1A to 32.53 tons in problem C7.1A. There are only minor differences between the column and brace weights of these two comparative examples. It should be noted that the choice of beam sections in problem C7.1A is entirely dependent on the non-economy beam section table input for this example. It is likely that extending the non-economy beam table in this case would result in a reduction of total beam weight for the plastic design solution.

A comparison of Figures 8 and 15 reveal a .92 ton column weight increase of C8.1A over C1.1A which is due to the weak beam - strong column constraint effects in column lines 2 and 4 of stories 1 through 8. Accompanying this column weight increase in C8.1A is a negligible beam weight decrease and absolutely no change in the bracing weight. It is interesting to note that column size changes to satisfy the weak beam - strong column constraint occured only in the interior column lines where two beams frame into a joint.

Comparisons of Figures 8 and 16 reveal an average weight increase of .66 tons each for beams, columns and braces. These weight changes are due to a beam size increase in beam 3 of story 18, column size changes in column lines 2, 3 and 4 of stories 20 and 22, and bracing size changes in stories 13 to 24. These changes are explained by the fact that the inclusion of column axial deformation effects increases the ultimate story shear associated with the P-delta effect. This, of course, increases the total story shear at collapse, necessitating the above design changes. Note that the bracing sections exhibit the greatest percentage increase in weight due to the fact that this increase in ultimate story shear is distributed primarily into the braced panel. This is consistent with the points discussed for the results of Problem Set 1.

An important point the user should be aware of when including column elongation and shortening effect in the P-detla computation in plastic design is that the corresponding results are very unpredictable. In some design solutions, an example of which is C9.1A, the effects will be consistent and expected, while in other solutions, not shown here, the effects will be unexpected. This is probably due to the arbitrary manner by which an equilibrium force distribution is generated. Because of this, it is advised that the user exercise some caution when using this capability.

The final example problem in Problem Set 2, C10.1A, is executed to present results of a more realistic design situation. In practical cases, columns are not generally braced against out-of-plane bending at points other than at column ends. The results of example C10.1A are therefore generated by removing the unrealistic laterally unbraced column length constraint of 72.0 inches and allowing the columns to act with no lateral bracing at points other than the column ends. This problem also has a plastic design convergence tolerance of 5 per cent as opposed to 10 percent for example C1.1A. The results of this problem are illustrated in Figure 17 and Table 3 and, compared to the results of C1.1A, reveal an expected increase in column weight (1.97 tons) over the column weight of problem C1.1A. This increase is due to the increased effect of the lateral torsional stability factor in the column design. Accompanying this increase in column weight is a corresponding decrease in beam weight due to the increased plastic moment capacity provided by the larger columns. In both example problem C1.1A and C10.1A, plastic design converged after two plastic design cycles; thus, it is very likely that the weight differences observed in problem C10.1A are due entirely to the longer laterally unbraced length with no effect of the smaller 5 per cent convergence tolerance observed.

A Note Regarding Elastic Design Results

Elastic design results, which include the effects of both elastic stress and elastic stiffness constraints as well as plastic design results, are also presented for example problem C1.1A through C7.1A. There results are more or less uniform for all these problems; therefore, these results may be generally described as follows. In all cases, the satisfaction of elastic design constraints produced striking beam and brace weight increases and very minimal weight changes in column total weights. And in all cases only beam weight increases were necessary to satisfy elastic stress constraints while only bracing changes were necessary to satisfy elastic stiffness constraints. There is, however, one interesting fact regarding the behavior of elastic design, and that is that in almost all of these problems, two elastic design cycles were necessary to satisfy the elastic stiffness constraint of an elastic relative story deflection limited to h/400 for all stories. This point is nicely illustrated in Figures 19, 20 and 21, and Table 5 which show the shape of the deflected structure after each design cycle. From this presentation it can be seen how the elastic design process fairly uniformly satisfies the elastic stiffness constraint of .36 inches for each story.

Summary of Results - Problem Set 3

This section describes the results of Problem Set 3 which are summarized in Table 4 and illustrated in Figure 18. A 6 story, 3 bay unbraced frame is used to generate the results of two example problems presented here, which are EX1, plastic design only including the effects of column effective lengths, and EX2, elastic stress design only using the beam and column yield stress of 36.0 ksi as the maximum elastic stress. Example problem EX2 is started with an initially assumed member property distribution as described in the input data listed earlier in this chapter.

A comparison of the results listed in Table 3 reveals a difference in total column weight between EX1 and EX2 of 1.42 tons (16.6%) which is quite a significant result in view of the fact that these results are for 6 story frames only. It may be concluded from this result that the effective lengths of columns will have a striking effect on the plastic design of columns in unbraced frames, especially for tall ones. For example, consider a 24 story, 3 bay unbraced frame whose member sizes, we will assume, are roughly equivalent to those of example problem C1.1A in which all effective member lengths are assumed equal to the actual member lengths to start. Now consider the beam and columns framing into the joint 1 of stories 20 and 21 as shown in Figure 22. One of the most practical methods of computing effective lengths for design purposes is described in Reference 2, Section 5; this method is used in PLADS I.

According to the alignment chart, Fig. C1.8.2 in Reference 2, with these relative stiffnesses, the effective length of column 20-1 is approximately equal to 4.75 times the actual length of column 20-1. It is evident, now, that during the iterative design process, employed in PLADS I, of satisfying AISC column interaction equations 2.4-2 and 2.4-3 (2, 11), a considerable burden will be placed on the column section table, requiring significantly heavier sections (box sections) to be input in addition to those existing column sections listed in APPENDIX I. Thus, it is clear that column effective lengths used in the plastic design of unbraced frames, tall ones in particular, will have a substantial effect on the outcome of the column design as expected.

A Note Regarding Execution Times for Examples

The majority of the 24 story example problems exhibited both plastic and elastic stress and stiffness designs to converge in two design cycles after an average of 34 minutes CPU time in 80 K words of core on a UNIVAC 1108 digital computer. Example EX1, plastic design only, converged in 3 design cycles after 2.3 minutes CPU times in 80 K words of core and example EX2, elastic stress and stiffness design only, executed in only .5 minutes in 80 K words of core.

Table 2. Summary of Results for Problem Set 1

	MATERIAL WEIGHT (TONS)				COST (DOLLARS)
Example	Beams	Columns	Bracing	Total	
Plastic Design					
C1.1A	28.33	102.35	7.23	137.91	55,162.39
C2.1A	30.55	104.03	5.70	140.28	56,111.65
C3.1A	30.69	108.89	6.02	145.59	58,236.27
C4.1A	30.38	115.52	5.42	151.33	60,530.59
C5.1A	29.03	105.44	10.25	144.72	57,888.00
Total Design					
C1.1A	37.18	102.35	8.74	148.27	59,306.15
C2.1A	35.52	104.03	6.44	145.99	58,396.32
C3.1A	39.12	108.89	8.06	156.07	62,428.94
C4.1A	43.47	118.16	11.94	173.57	69,427.30
C5.1A	36.35	105.44	11.25	153.25	61,299.51

Table 3. Summary of Results for Problem Set 2

Example	MATERIAL WEIGHT (TONS)				COST (DOLLARS)
	Beams	Columns	Bracing	Total	
Plastic Design					
C6.1A	28.48	29.29-A36 52.80-A441	7.52	118.00	51,423.05
C7.1A	32.53	102.49	7.27	142.29	56,914.87
C8.1A	28.31	103.27	7.23	138.82	55,526.85
C9.1A	28.42	103.01	7.47	138.90	55,558.70
C10.1A	28.25	104.32	7.32	139.88	55,950.86
Total Design					
C6.1A	40.24	29.23-A36 52.80-A441	10.14	132.41	57,189.11
C7.1A	32.53	102.49	7.27	142.29	56,914.87

Table 4. Summary of Results for Problem Set 3

MATERIAL WEIGHT (TONS)			
Example	Beams	Columns	Total
EX1-Plastic Design	6.86	10.44	17.30
EX2-Elastic Stress Design	7.80	8.66	16.46

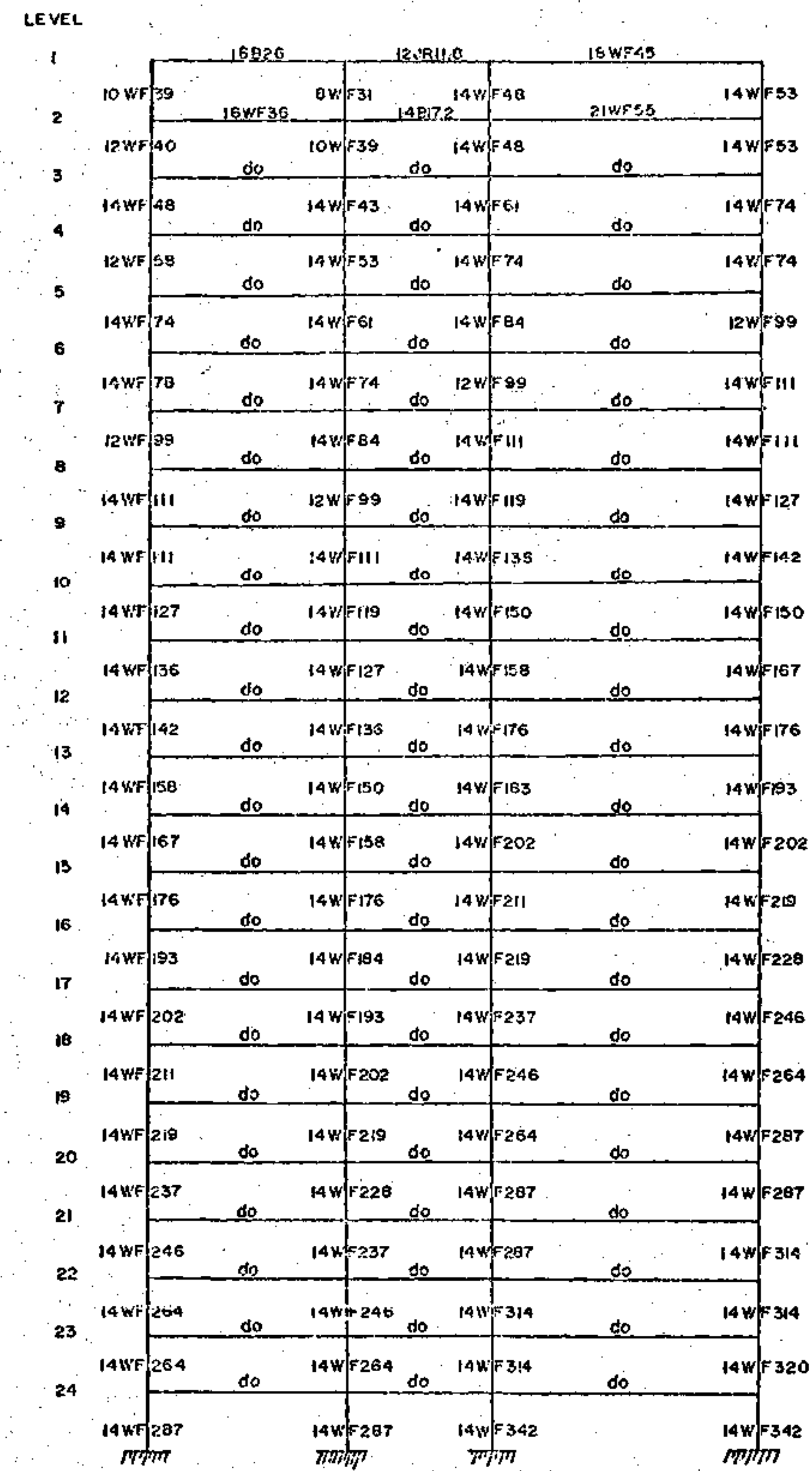
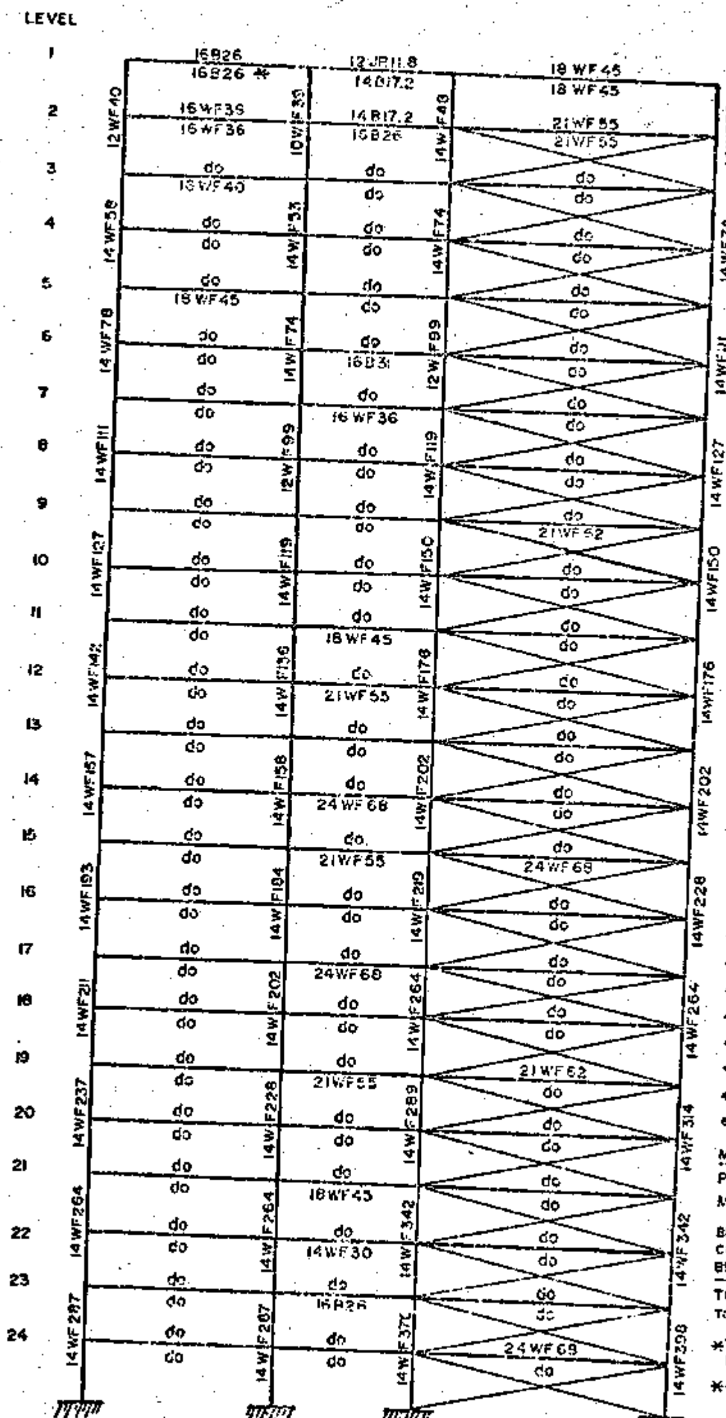


Figure 7. Gravity Design - All of Problem Set 1.



DESIGN CONDITIONS

1. PLASTIC DESIGN (10% CONVERGENCE TOLERANCE)
2. PANEL MOMENT ACTION PERMITTED
3. BRACING PERMITTED IN BAY 3 ONLY
4. ELASTIC STRESS DESIGN ($\sigma \leq \sigma_y$)
5. ELASTIC STIFFNESS DESIGN ($\Delta/H \leq 1/400$)

BRACING SIZES (DOUBLE ANGLES, JL)

SIZE	STORY	TYPE **
PLASTIC DESIGN		
$1 \times 1 \times \frac{1}{8}$	2,3	1,2
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{8}$	4	1,2
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{1}{8}$	5	1,2
$2 \times 2 \times \frac{1}{8}$	6	1,2
$2 \times 2 \times \frac{3}{16}$	7,8	1,2
$3 \times 2 \times \frac{3}{16}$	9,10	1,2
$3 \times 2\frac{1}{2} \times \frac{1}{4}$	11,12,13	1,2
$4 \times 3 \times \frac{1}{4}$	14,15,16	1,2
$3 \times 2\frac{1}{2} \times \frac{3}{8}$	17	1,2
$4 \times 3 \times \frac{5}{16}$	18	1,2
$4 \times 3\frac{1}{2} \times \frac{5}{16}$	19	1,2
$4 \times 3\frac{1}{2} \times \frac{7}{16}$	20	1,2
$4 \times 3\frac{1}{2} \times \frac{3}{8}$	21	1,2
$4 \times 3 \times \frac{7}{16}$	22	1,2
$4 \times 3 \times \frac{1}{2}$	23,24	1,2
TOTAL DESIGN (PLASTIC DESIGN PLUS ELASTIC STIFFNESS DESIGN PLUS ELASTIC STRESS DESIGN PLUS FINAL PLASTIC DESIGN CHECK)		
$1 \times 1 \times \frac{1}{8}$	2,3 8,9	1,2 1
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{8}$	4	1,2
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{1}{8}$	5	1,2
$2 \times 2 \times \frac{1}{8}$	6	2
$2 \times 2 \times \frac{3}{16}$	7,8	2
$3 \times 2 \times \frac{3}{16}$	8 9,10	1 2
$3 \times 2\frac{1}{2} \times \frac{1}{4}$	7 11,12,13	1 2
$3 \times 2\frac{1}{2} \times \frac{3}{8}$	10 17	1 2
$4 \times 3\frac{1}{2} \times \frac{5}{16}$	11,13 19	1 2
$4 \times 3 \times \frac{3}{8}$	12,17	1
$4 \times 3\frac{1}{2} \times \frac{3}{8}$	14,16 21	1 2
$4 \times 3 \times \frac{1}{4}$	14,15,16	2
$4 \times 3 \times \frac{7}{16}$	15,19,22	1
$4 \times 3 \times \frac{5}{16}$	22 18	2 2
$4 \times 3\frac{1}{2} \times \frac{7}{16}$	19 20	1 2
$4 \times 3 \times \frac{1}{2}$	20,23,24	1
$6 \times 4 \times \frac{3}{8}$	23,24 21	2 1

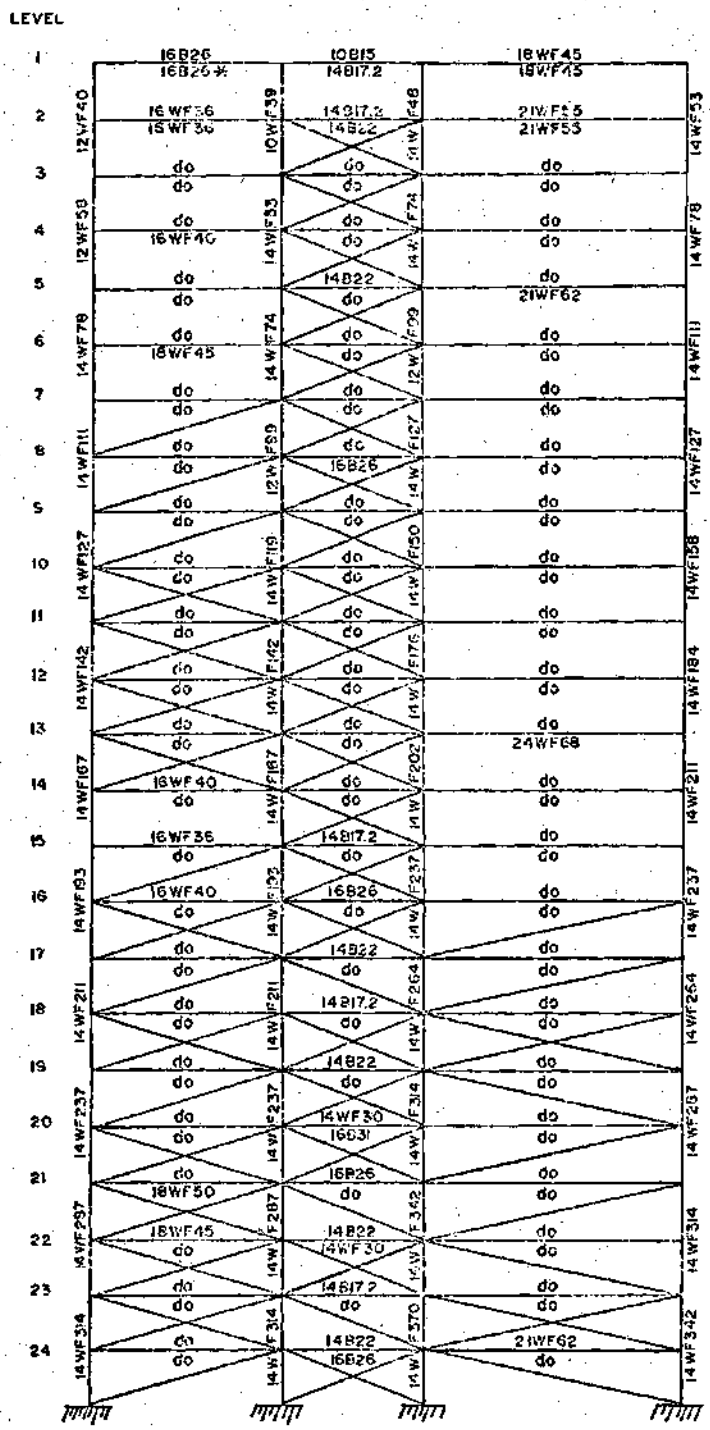
MATERIAL WEIGHTS AND COSTS

PLASTIC DESIGN MEMBER	WEIGHT	TOTAL DESIGN WEIGHT
BEAMS	28.52 TONS	37.18 TONS
COLUMNS	102.35 TONS	102.35 TONS
BRACING	7.23 TONS	6.74 TONS
TOTAL WEIGHT	137.91 TONS	146.27 TONS
TOTAL COST	\$ 55,152.39	\$ 59,303.15

* TOP LABEL — PLASTIC DESIGN RESULTS
BOTTOM LABEL — TOTAL DESIGN DIFFERENCES

** TYPE = 1 = TENSION, WIND FROM THE RIGHT
2 = TENSION, WIND FROM THE LEFT

Figure 8. Example Problem C1.1A



DESIGN CONDITIONS

1. PANEL MOMENT ACTION PERMITTED
2. BRACING PERMITTED IN ALL BAYS
3. PLASTIC DESIGN (10% CONVERGENCE TOLERANCE)
4. ELASTIC STRESS DESIGN ($\sigma_{max} \leqslant \sigma_y$)
5. ELASTIC STIFFNESS DESIGN ($\Delta/H \leqslant 1/400$)

BRACING SIZES (DOUBLE ANGLES, ⅃L)

SIZE	STORY	BAY	TYPE **
PLASTIC DESIGN			
1x1x1/8	10	1	1
	7,11,12	1	2
	2,11,14	2	1
	2	2	2
	18,22	3	1
	20	3	2
1¼x1¼x1/8	13	1	1
	8,16	1	2
	3	2	1
	3,16	2	2
1½x1½x1/8	10,17	1	2
	15	2	2
	16,21	3	2
1¾x1¾x1/8	9	1	2
	4,23	2	1
2x2x1/8	4	2	2
	23	1	1
	20	1	2
	5	2	1
	5,8,9	2	2
	18	3	2
2x2x3/16	12,22	1	1
	13	1	2
	6,7,12,17,18	2	1
	6,7,10	2	2
	23	3	2
3x2x3/16	10	1	1
	8,10	2	1
3x2½x¼	13	2	2
	11,14,18,20,21	1	1
	15,18,19	1	2
	9,13,16,24	2	1
	8,12,16,22	2	2
	19	3	2
4x3x¼	17	1	1
	24	1	2
	19,24	2	2
3x2½x3/8	17	3	2
	22	1	2
	15,19,20,21	2	1
	14	3	2
4x3½x5/16	24	3	1
	23	3	1
4x3x3/8	21,23	1	2
	22	2	1
4x3½x3/8	20	2	2
TOTAL DESIGN (PLASTIC DESIGN PLUS ELASTIC STRESS DESIGN PLUS ELASTIC STIFFNESS DESIGN PLUS FINAL PLASTIC DESIGN CHECK)			
1x1x1/8	10	1	1
	7,11,12	1	2
	2	2	1,2
	18,22	3	1
1¼x1¼x1/8	20	3	2
	13	1	1
	8,16	1	2
	3	2	1
	3,18	2	2
1½x1½x1/8	10,17	1	2
	11	2	1
	16,21	3	2
1¾x1¾x1/8	9	1	2
	4,23	2	1
	4	2	2
2x2x1/8	23	1	1
	20	1	2
	5	2	1
	8	2	2
	18	3	2
2x2x3/16	12,22	1	1
	13	1	2
	17,18,5	2	1
	6,10,9	2	2
	23	3	2
3x2x3/16	16	1	1
	14	2	1
	13,7	2	2
3x2½x¼	11,14,18,20,21	1	1
	15,18,19	1	2
	6,7,12,24	2	1
	11,15,16,22	2	2
	10	3	2
4x3x¼	17	1	1
	24	1	2
	19,24	2	2
3x2½x3/8	17	3	2
	22	1	2
	8,10,19,20,21	2	1
4x3½x5/16	24	3	1
	14	2	1
	12	2	2
	23	3	1
4x3x3/8	21,23	1	2
	22,?	2	1
4x3½x3/8	14,20	2	2
	15	2	1
4x3x½	13	2	1

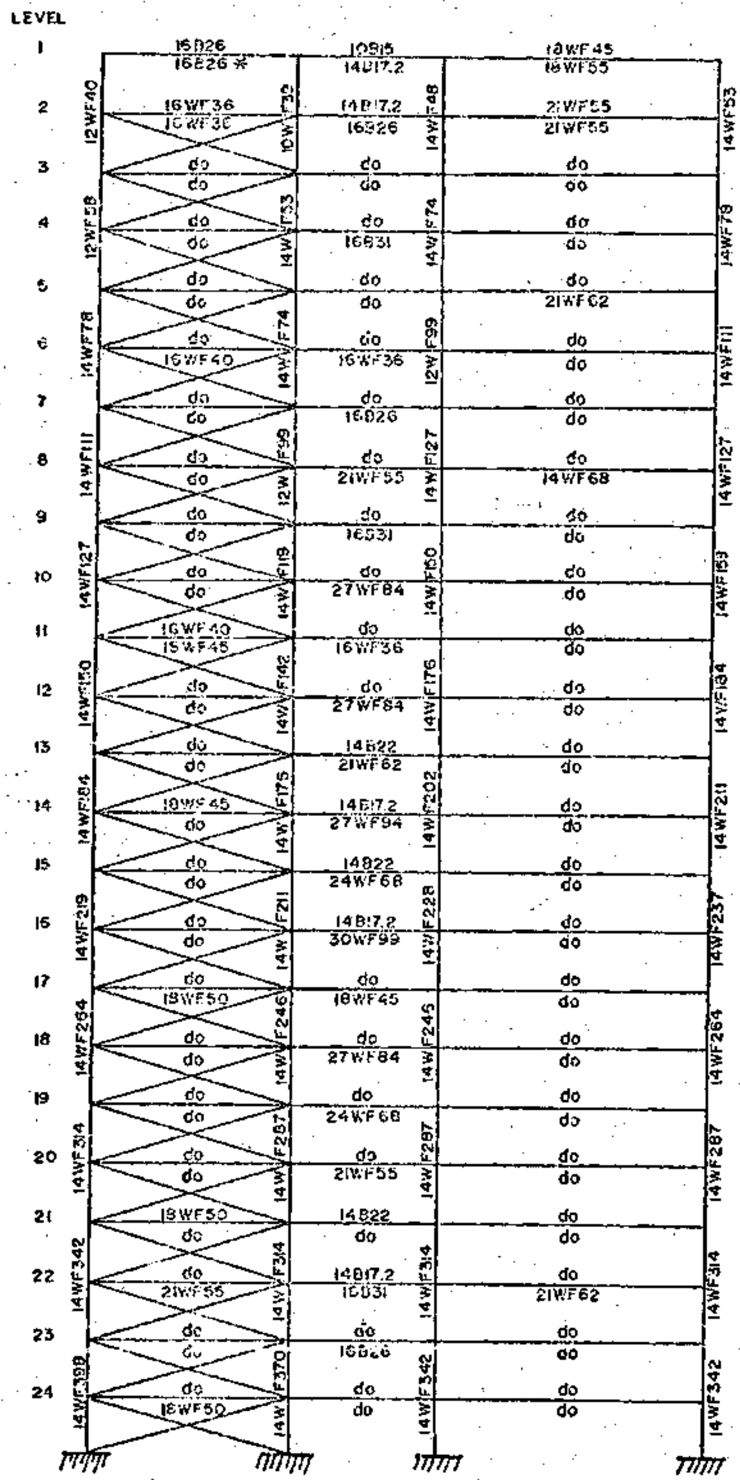
MATERIAL WEIGHTS AND COSTS

MEMBER	PLASTIC DESIGN WEIGHT	TOTAL DESIGN WEIGHT
BEAMS	30.55 TONS	35.52 TONS
COLUMNS	104.03 TONS	104.03 TONS
BRACING	5.70 TONS	6.44 TONS
TOTAL WT.	140.28 TONS	145.99 TONS
TOTAL COST	$ 56,111.65	$ 58,396.32

* TOP LABEL – PLASTIC DESIGN RESULTS
BOTTOM LABEL – TOTAL DESIGN DIFFERENCES

** TYPE – 1 – TENSION, WIND FROM THE RIGHT
2 – TENSION, WIND FROM THE LEFT

Figure 9. Example Problem C2.1A



DESIGN CONDITIONS

1. MOMENT ACTION PERMITTED
2. BRACING PERMITTED IN BAY I ONLY
3. PLASTIC DESIGN (10% CONVEGENCE TOLERANCE)
4. ELASTIC STRESS DESIGN ($\sigma_{max} \leq \sigma_y$)
5. ELASTIC STIFFNESS DESIGN ($\Delta/H \leq 1/400$)

BRACING SIZES (DOUBLE ANGLES, ⅃L)

SIZE	STORY	TYPE **
PLASTIC DESIGN		
$1 \times 1 \times \frac{1}{8}$	2,3	1,2
$1\frac{1}{2} \times 1\frac{1}{2} \times \frac{1}{8}$	4	1,2
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{1}{8}$	5	1,2
$2 \times 2 \times \frac{1}{8}$	6	1,2
$2 \times 2 \times \frac{3}{16}$	7,8	1,2
$3 \times 2 \times \frac{3}{16}$	9,10	1,2
$3 \times 2\frac{1}{2} \times \frac{1}{4}$	11,12	1,2
$4 \times 3 \times \frac{1}{4}$	13	1,2
$3\frac{1}{2} \times 3 \times \frac{5}{16}$	14 15	1,2 2
$4 \times 3 \times \frac{5}{16}$	15 16	1 2
$4 \times 3\frac{1}{2} \times \frac{5}{16}$	16 17,19	1 2
$4 \times 3 \times \frac{3}{8}$	17,19 18,20	1 2
$4 \times 3\frac{1}{2} \times \frac{3}{8}$	20,21 21	1 2
$4 \times 3\frac{1}{2} \times \frac{7}{16}$	22	1,2
$4 \times 3 \times \frac{1}{2}$	23	1,2
$6 \times 3\frac{1}{2} \times \frac{3}{8}$	24	1,2
TOTAL DESIGN (PLASTIC DESIGN PLUS ELASTIC STRESS DESIGN PLUS ELASTIC STIFFNESS DESIGN PLUS FINAL PLASTIC DESIGN CHECK)		
$1 \times 1 \times \frac{1}{8}$	2,3	1,2
$1\frac{1}{2} \times 1\frac{1}{2} \times \frac{1}{8}$	4	1
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{1}{8}$	4,5 5	2 1
$2 \times 2 \times \frac{1}{8}$	6	1
$2 \times 2 \times \frac{3}{16}$	7 8	1,2 1
$3 \times 2 \times \frac{3}{16}$	9	1,2
$3 \times 2\frac{1}{2} \times \frac{1}{4}$	11 10	1,2 1
$4 \times 3 \times \frac{1}{4}$	6,13	2
$3 \times 2\frac{1}{2} \times \frac{3}{8}$	12,13 13	1 2
$3 \times 2 \times \frac{1}{2}$	17	2
4x3[illegible]	14,15	1
$3\frac{1}{2} \times 3 \times \frac{7}{16}$	21	1
$4 \times 3 \times \frac{7}{16}$	8 16,17,19	2 1
$4 \times 3\frac{1}{2} \times \frac{7}{16}$	18,20 22	1 1,2
$4 \times 3 \times \frac{1}{2}$	23	1,2
$6 \times 3\frac{1}{2} \times \frac{3}{8}$	24	1,2
$6 \times 4 \times \frac{3}{8}$	10,19,20	2
$5 \times 3 \times \frac{1}{2}$	21	2
$6 \times 3\frac{1}{2} \times \frac{1}{2}$	18	2
$7 \times 4 \times \frac{7}{16}$	12	2
$6 \times 4 \times \frac{7}{16}$	16	2
$8 \times 4 \times \frac{1}{2}$	14	2

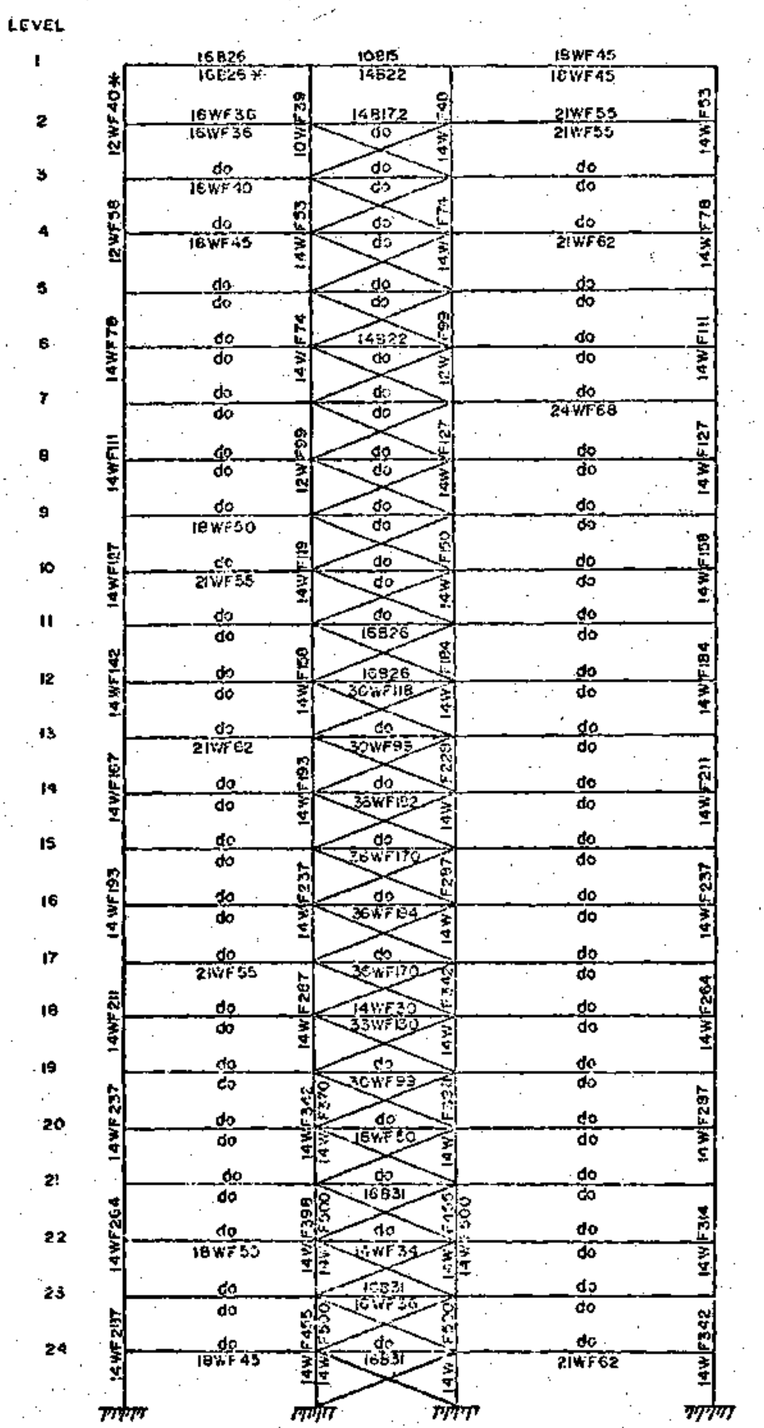
MATERIAL WEIGHTS AND COSTS

MEMBER	PLASTIC DESIGN WEIGHT	TOTAL DESIGN WEIGHT
BEAMS	30.69 TONS	36.12 TONS
COLUMNS	108.89 TONS	109.89 TONS
BRACING	6.02 TONS	8.06 TONS
TOTAL WT.	145.59 TONS	156.07 TONS
TOTAL COST	$ 58,237.27	$ 62,420.94

* TOP LABEL – PLASTIC DESIGN RESULTS
BOTTOM LABEL – TOTAL DESIGN DIFFERENCES

** TYPE • 1 = TENSION, WIND FROM THE RIGHT
2 = TENSION, WIND FROM THE LEFT

Figure 10. Example Problem C3.1A



DESIGN CONDITIONS

1. MOMENT ACTION PERMITTED
2. BRACING PERMITTED IN BAY 2 ONLY
3. PLASTIC DESIGN (10% CONVERGENCE TOLERANCE)
4. ELASTIC STRESS DESIGN ($\sigma_{max} \leq \sigma_y$)
5. ELASTIC STIFFNESS DESIGN ($\Delta/H \leq 1/400$)

BRACING SIZES (DOUBLE ANGLES, JL)

SIZE	STORY	TYPE **
PLASTIC DESIGN		
$1 \times 1 \times \frac{1}{8}$	2	1,2
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{8}$	3	1,2
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{1}{8}$	4	1,2
$2 \times 2 \times \frac{1}{8}$	5	1,2
$2 \times 2 \times \frac{3}{16}$	6,7	1,2
$3 \times 2 \times \frac{3}{16}$	8	1,2
$3 \times 2\frac{1}{2} \times \frac{1}{4}$	9,10	1,2
$4 \times 3 \times \frac{1}{4}$	11	1,2
$3 \times 2\frac{1}{2} \times \frac{5}{16}$	12	1
$4 \times 3 \times \frac{3}{16}$	12 14	2 1
$4 \times 3\frac{1}{2} \times \frac{5}{16}$	13,15	1
$4 \times 3 \times \frac{3}{8}$	13,14,15	2
$4 \times 3\frac{1}{2} \times \frac{3}{8}$	16 17	1,2 1
$4 \times 3 \times \frac{7}{16}$	17 18	2 1
$4 \times 3\frac{1}{2} \times \frac{7}{16}$	19	1,2
$4 \times 3 \times \frac{1}{2}$	18 20	2 1,2
$6 \times 3\frac{1}{2} \times \frac{3}{8}$	21	1,2
$6 \times 4 \times \frac{3}{8}$	22	1,2
$6 \times 3 \times \frac{1}{2}$	23	1,2
$5 \times 3\frac{1}{2} \times \frac{1}{2}$	24	1,2
TOTAL DESIGN (PLASTIC DESIGN PLUS ELASTIC STRESS DESIGN PLUS ELASTIC STIFFNESS DESIGN PLUS FINAL PLASTIC DESIGN CHECK)		
$1 \times 1 \times \frac{1}{8}$	2	1,2
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{8}$	3	1,2
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{1}{8}$	4	1,2
$2 \times 2 \times \frac{1}{8}$	5	2
$2 \times 2 \times \frac{3}{16}$	5 6,7	1 2
$3 \times 2\frac{1}{2} \times \frac{1}{4}$	7 8	1 2
$4 \times 3 \times \frac{1}{4}$	8 11	1 2
$4 \times 3\frac{1}{2} \times \frac{3}{16}$	9	1
$4 \times 3 \times \frac{3}{8}$	9,13,15	2
$4 \times 3 \times \frac{7}{16}$	17	2
$4 \times 3\frac{1}{2} \times \frac{7}{16}$	19	2
$6 \times 3\frac{1}{2} \times \frac{3}{8}$	21	2
$6 \times 4 \times \frac{3}{8}$	22,9	1
$6 \times 3 \times \frac{1}{2}$	23	1,2
$5 \times 3\frac{1}{2} \times \frac{1}{2}$	24	1,2
$6 \times 6 \times \frac{7}{16}$	10	1
$6 \times 6 \times \frac{1}{2}$	10	2
$6 \times 6 \times \frac{3}{4}$	11,12,13,14,15,16, 17,18,19,20,21 12,15,16,18,20,22,14	 1 2

MATERIAL WEIGHTS AND COSTS

MEMBER	PLASTIC DESIGN WEIGHT	TOTAL DESIGN WEIGHT
BEAMS	30.58 TONS	45.47 TONS
COLUMNS	115.53 TONS	119.16 TONS
BRACING	5.42 TONS	11.94 TONS
TOTAL WT.	151.33 TONS	173.57 TONS
TOTAL COST	\$ 60,530.59	\$ 69,427.30

* TOP LABEL – PLASTIC DESIGN RESULTS
BOTTOM LABEL – TOTAL DESIGN DIFFERENCES

** TYPE = 1 = TENSION, WIND FROM THE RIGHT
2 = TENSION, WIND FROM THE LEFT

Figure 11. Example Problem C4.1A

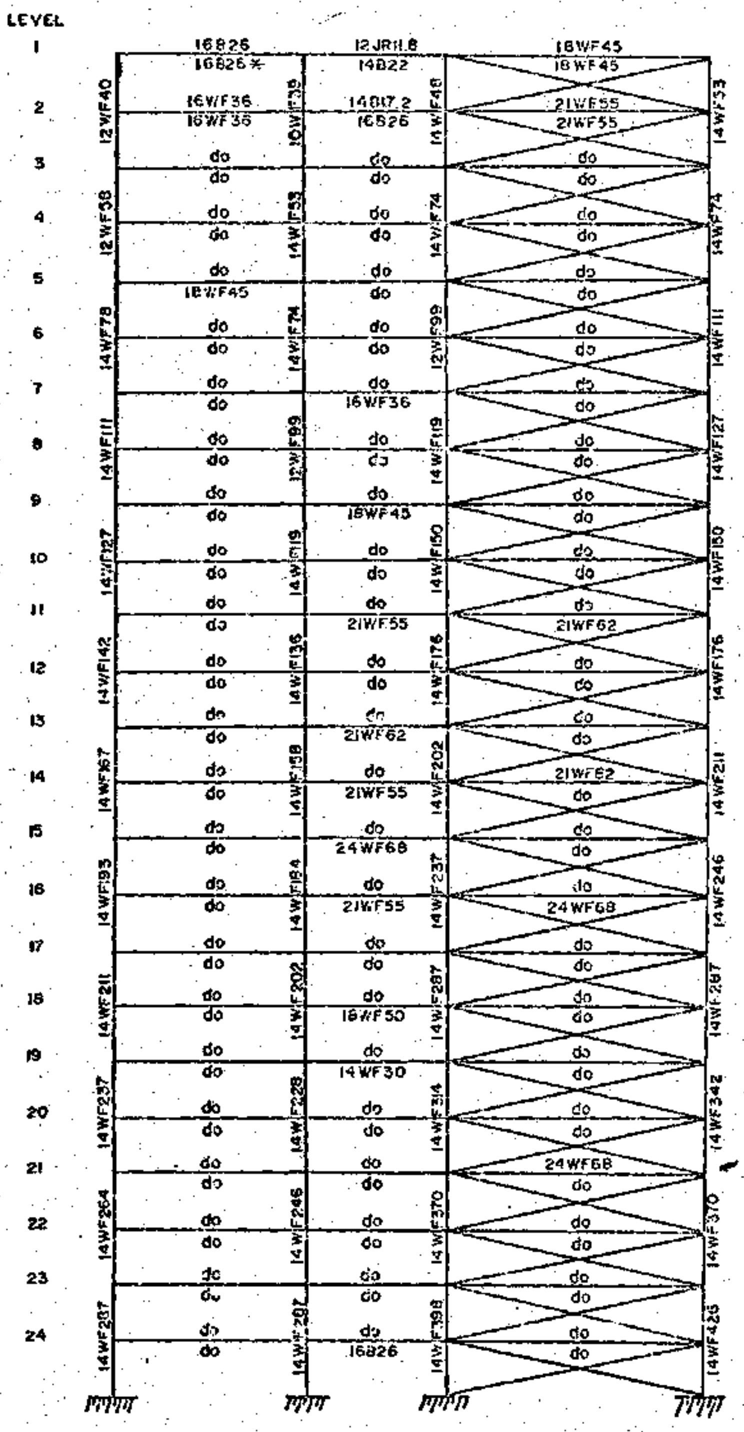


Figure 12. Example Problem C5.1A

DESIGN CONDITIONS

1. NO MOMENT ACTION PERMITTED
2. TRUSS ACTION ONLY IN BAY 3
3. PLASTIC DESIGN (10% CONVERGENCE TOLERANCE)
4. ELASTIC STRESS DESIGN ($\sigma_{max} \leq \sigma_y$)
5. ELASTIC STIFFNESS DESIGN ($\Delta/H \leq 1/400$)

BRACING SIZES (DOUBLE ANGLES, JL)

SIZE	STORY	TYPE **
PLASTIC DESIGN		
$1 \times 1 \times \frac{1}{8}$	1	1,2
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{8}$	2	1,2
$2 \times 2 \times \frac{1}{8}$	3	1,2
$2 \times 2 \times \frac{1}{8}$	4	1,2
$3 \times 2 \times \frac{3}{16}$	5	1,2
$3 \times 2\frac{1}{2} \times \frac{1}{4}$	6,7,8	1,2
$4 \times 3 \times \frac{1}{4}$	9,10	1,2
$3 \times 2\frac{1}{2} \times \frac{3}{8}$	11,12	1,2
$4 \times 3 \times \frac{5}{16}$	13	1,2
$4 \times 3\frac{1}{2} \times \frac{5}{16}$	14	1,2
$4 \times 3 \times \frac{3}{8}$	15, 16	1,2
$4 \times 3\frac{1}{2} \times \frac{3}{8}$	17	1,2
$4 \times 3 \times \frac{7}{16}$	18	1,2
$4 \times 3\frac{1}{2} \times \frac{7}{16}$	19	1,2
$4 \times 3 \times \frac{1}{2}$	20	1,2
$6 \times 3\frac{1}{2} \times \frac{3}{8}$	21,22	1,2
$6 \times 4 \times \frac{3}{8}$	23	1,2
$5 \times 3 \times \frac{1}{2}$	24	1,2

TOTAL DESIGN (PLASTIC DESIGN PLUS ELASTIC STRESS DESIGN PLUS ELASTIC STIFFNESS DESIGN PLUS FINAL PLASTIC DESIGN CHECK)

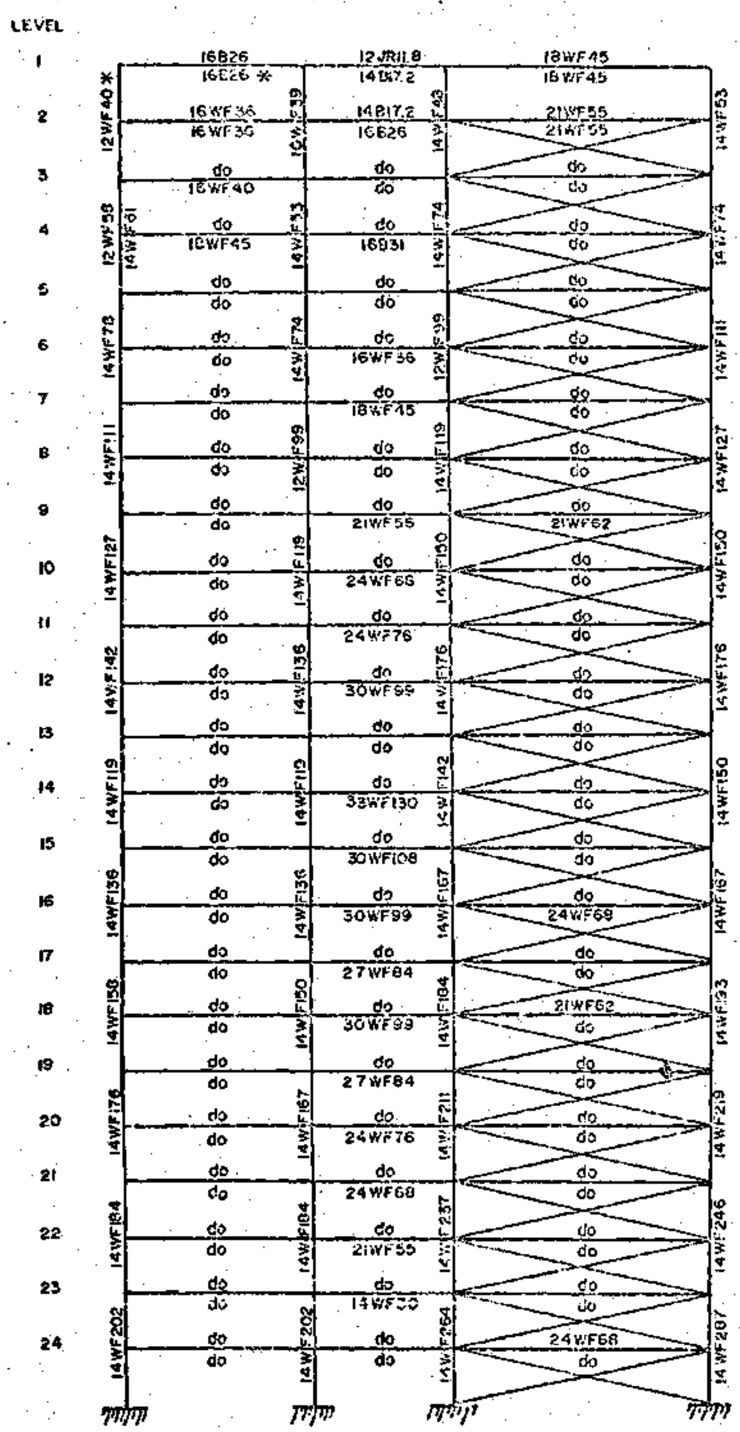
SIZE	STORY	TYPE **
$1 \times 1 \times \frac{1}{8}$	1	1,2
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{8}$	2	1,2
$2 \times 2 \times \frac{1}{8}$	3	1,2
$2 \times 2 \times \frac{3}{16}$	4	1,2
$3 \times 2 \times \frac{3}{16}$	5	1,2
$3 \times 2\frac{1}{2} \times \frac{1}{4}$	6,7,8	2
$4 \times 3 \times \frac{1}{4}$	6,7 9,10	1 2
$3 \times 2\frac{1}{2} \times \frac{3}{8}$	11,12	2
$4 \times 3 \times \frac{5}{16}$	8 13	1 2
$4 \times 3\frac{1}{2} \times \frac{5}{16}$	9 14	1 2
$4 \times 3 \times \frac{3}{8}$	15,16	2
$4 \times 3\frac{1}{2} \times \frac{3}{8}$	10 17	1 2
$4 \times 3 \times \frac{7}{16}$	11,12,13 18	1 2
$4 \times 3\frac{1}{2} \times \frac{7}{16}$	14, 15	1
$4 \times 3 \times \frac{1}{2}$	17 21	1 1,2
$6 \times 3\frac{1}{2} \times \frac{3}{8}$	16 22	1 1,2
$6 \times 4 \times \frac{3}{8}$	23	1,2
$5 \times 3 \times \frac{1}{2}$	18 24	1 1,2

MATERIAL WEIGHTS AND COSTS

MEMBER	PLASTIC DESIGN WEIGHT	TOTAL DESIGN WEIGHT
BEAMS	29.03 TONS	30.56 TONS
COLUMNS	105.44 TONS	105.44 TONS
BRACING	10.25 TONS	11.25 TONS
TOTAL WT.	144.72 TONS	153.25 TONS
TOTAL COST	\$ 57,868.00	\$ 61,299.57

* TOP LABEL – PLASTIC DESIGN RESULTS
BOTTOM LABEL – TOTAL DESIGN DIFFERENCES

** TYPE 1 – TENSION, WIND FROM THE RIGHT
2 – TENSION, WIND FROM THE LEFT



DESIGN CONDITIONS

1. MOMENT ACTION PERMITTED
2. BRACING PERMITTED IN BAY 3 ONLY
3. A441, 50 ksi STEEL USED FOR ALL COLUMNS IN STORIES 13 THROUGH 24
4. PLASTIC DESIGN (10% CONVERGENCE TOLERANCE)
5. ELASTIC STRESS DESIGN ($\sigma_{max} \leq \sigma_y$)
6. ELASTIC STIFFNESS DESIGN ($\Delta/H \leq 1/400$)

BRACING SIZES (DOUBLE ANGLES, JL)

SIZE	STORY	TYPE **
PLASTIC DESIGN		
$1 \times 1 \times \frac{1}{8}$	2,3	1,2
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{8}$	4	1,2
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{1}{4}$	5	1,2
$2 \times 2 \times \frac{1}{8}$	6	1,2
$2 \times 2 \times \frac{3}{16}$	7,8	1,2
$3 \times 2 \times \frac{3}{16}$	9,10	1,2
$3 \times 2\frac{1}{2} \times \frac{1}{4}$	11,12,13	1,2
$4 \times 3 \times \frac{1}{4}$	14,15,16	1,2
$3 \times 2\frac{1}{2} \times \frac{3}{8}$	17	1,2
$4 \times 3 \times \frac{3}{8}$	18	1,2
$4 \times 3\frac{1}{2} \times \frac{3}{8}$	19,20	1,2
$4 \times 3 \times \frac{7}{16}$	21	1,2
$4 \times 3\frac{1}{2} \times \frac{7}{16}$	22	1,2
$4 \times 3 \times \frac{1}{2}$	23,24	1,2

TOTAL DESIGN (PLASTIC DESIGN PLUS ELASTIC STRESS DESIGN PLUS ELASTIC STIFFNESS DESIGN PLUS FINAL PLASTIC DESIGN CHECK)

SIZE	STORY	TYPE **
$1 \times 1 \times \frac{1}{8}$	2,3	1,2
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{8}$	4	2
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{1}{8}$	5	2
$2 \times 2 \times \frac{1}{8}$	4	1
$2 \times 2 \times \frac{3}{16}$	6 7,8	2 2
$3 \times 2 \times \frac{3}{16}$	5 9,10	1 2
$3 \times 2\frac{1}{2} \times \frac{3}{16}$	11,12,13	2
$4 \times 3 \times \frac{1}{4}$	6,7 14,15,16	1 2
$3 \times 2\frac{1}{2} \times \frac{3}{8}$	17	2
$4 \times 3\frac{1}{2} \times \frac{5}{16}$	8,9	1
$4 \times 3 \times \frac{3}{8}$	18	2
$4 \times 3\frac{1}{2} \times \frac{3}{8}$	10,12 19,20	1 2
$4 \times 3 \times \frac{7}{16}$	11 21	1 2
$4 \times 3\frac{1}{2} \times \frac{7}{16}$	13 22	1 2
$4 \times 3 \times \frac{1}{2}$	23,24	1,2
$6 \times 3\frac{1}{2} \times \frac{3}{8}$	17	1
$6 \times 4 \times \frac{3}{8}$	16,21	1
$6 \times 3 \times \frac{1}{2}$	14,16,19,20	1
$6 \times 3\frac{1}{2} \times \frac{1}{2}$	16	1
$6 \times 4 \times \frac{7}{16}$	22	1

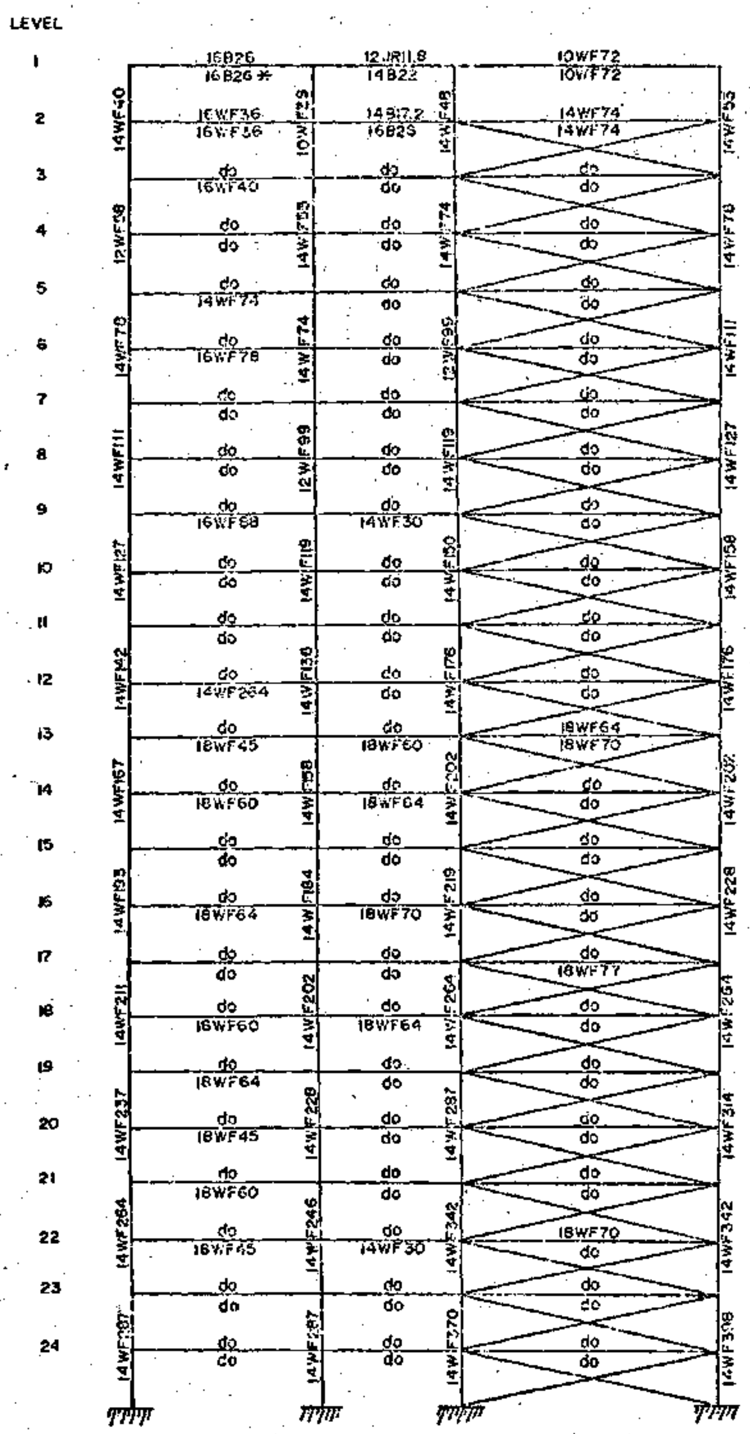
MATERIAL WEIGHTS AND COSTS

MEMBER	PLASTIC DESIGN WEIGHT	TOTAL DESIGN WEIGHT
BEAMS	28.48 TONS	40.28 TONS
COLUMNS		
36 ksi	29.20 TONS	29.23 TONS
50 ksi	52.80 TONS	52.80 TONS
BRACING	7.52 TONS	10.14 TONS
TOTAL WT.	118.00 TONS	132.41 TONS
TOTAL COST	\$ 51,423.05	\$ 57,199.11

* TOP LABEL — PLASTIC DESIGN RESULTS
BOTTOM LABEL — TOTAL DESIGN DIFFERENCES

** TYPE: 1 = TENSION, WIND FROM THE RIGHT
2 = TENSION, WIND FROM THE LEFT

Figure 13. Example Problem C6.1A



DESIGN CONDITIONS

1. MOMENT ACTION PERMITTED
2. BRACING PERMITTED IN BAY 3 ONLY
3. BEAM DEPTH CONSTAINTS:
   17.0 IN. ALL BEAMS STORIES 1 THROUGH 12
   20.0 IN. ALL BEAMS STORIES 13 THROUGH 24
4. PLASTIC DESIGN (10% CONVERGENCE TOLERANCE)
5. ELASTIC STRESS DESIGN ($\sigma_{max} \leq \sigma_y$)
6. ELASTIC STIFFNESS DESIGN ($\Delta/H \leq 1/400$)

BRACING SIZES (DOUBLE ANGLES, ⅃L)

SIZE	STORY	TYPE **
PLASTIC DESIGN		
$1 \times 1 \times \frac{1}{8}$	2,3	1,2
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{8}$	4	1,2
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{1}{8}$	5	1,2
$2 \times 2 \times \frac{1}{8}$	6	1,2
$2 \times 2 \times \frac{3}{16}$	7,8	1,2
$3 \times 2 \times \frac{3}{16}$	9,10	1,2
$3 \times 2\frac{1}{2} \times \frac{1}{4}$	11,12,13	1,2
$4 \times 3 \times \frac{1}{4}$	14,15,16	1,2
$3 \times 2\frac{1}{2} \times \frac{3}{8}$	17	1,2
$4 \times 3 \times \frac{5}{16}$	18	1,2
$4 \times 3\frac{1}{2} \times \frac{5}{16}$	19	1,2
$4 \times 3 \times \frac{3}{8}$	20	1,2
$4 \times 3\frac{1}{2} \times \frac{3}{8}$	21	1,2
$4 \times 3 \times \frac{7}{16}$	22	1,2
$4 \times 3 \times \frac{1}{2}$	23	1,2
$6 \times 3\frac{1}{2} \times \frac{5}{8}$	24	1,2
TOTAL DESIGN (PLASTIC DESIGN PLUS ELASTIC STRESS DESIGN PLUS ELASTIC STIFFNESS DESIGN PLUS FINAL PLASTIC DESIGN CHECK)		
$1 \times 1 \times \frac{1}{8}$	2,3	1,2
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{8}$	4	1,2
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{1}{8}$	5	1,2
$2 \times 2 \times \frac{1}{8}$	6	2
$2 \times 2 \times \frac{3}{16}$	7,8	2
$3 \times 2 \times \frac{3}{16}$	6 9,10	1 2
$3 \times 2\frac{1}{2} \times \frac{1}{4}$	7 11,12,13	1 2
$4 \times 3 \times \frac{1}{4}$	8,9 14,16	1 2
$3 \times 2\frac{1}{2} \times \frac{3}{8}$	17	2
$4 \times 3 \times \frac{5}{16}$	10 15,18	1 2
$4 \times 3\frac{1}{2} \times \frac{5}{16}$	11 19	1 2
$4 \times 3 \times \frac{3}{8}$	12,13	1
$4 \times 3\frac{1}{2} \times \frac{3}{8}$	21	2
$4 \times 3 \times \frac{7}{16}$	14,16,22 22	1 2
$4 \times 3\frac{1}{2} \times \frac{7}{16}$	15,17 20	1 2
$4 \times 3 \times \frac{1}{2}$	18,19,20,23 23	1 2
$6 \times 3\frac{1}{2} \times \frac{5}{8}$	21,24 24	1 2

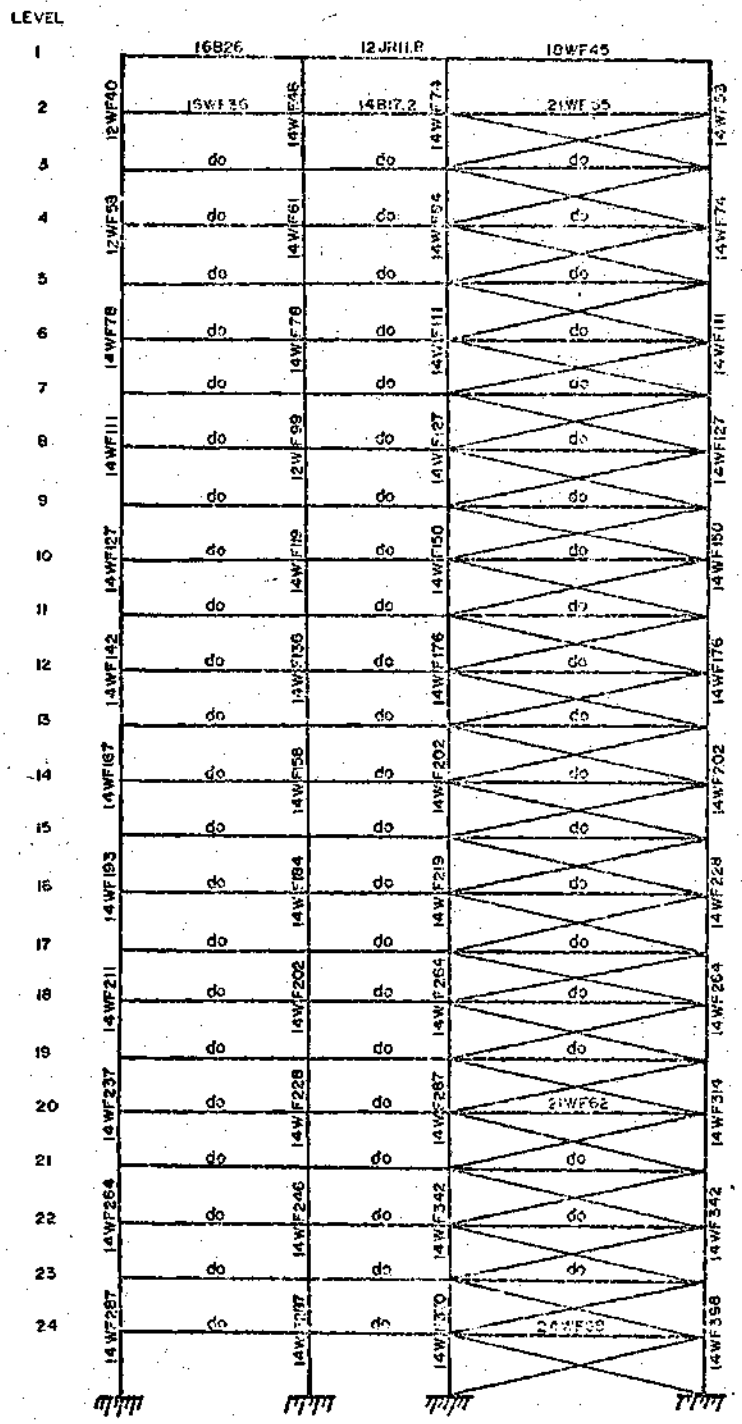
MATERIAL WEIGHTS AND COSTS

MEMBER	PLASTIC DESIGN WEIGHT	TOTAL DESIGN WEIGHT
BEAMS	32.53 TONS	47.19 TONS
COLUMNS	102.49 TONS	102.49 TONS
BRACING	7.27 TONS	9.03 TONS
TOTAL WT.	142.29 TONS	158.71 TONS
TOTAL COST	\$ 56,914.67	\$ 63,482.23

* TOP LABEL – PLASTIC DESIGN RESULTS
BOTTOM LABEL – TOTAL DESIGN DIFFERENCES

** TYPE = 1 = TENSION, WIND FROM THE RIGHT
2 = TENSION, WIND FROM THE LEFT

Figure 14. Example Problem C7.1A



DESIGN CONDITIONS

1. MOMENT ACTION PERMITTED
2. BRACING PERMITTED IN BAY 3 ONLY
3. WEAK BEAM – STRONG COLUMN CONSTRAINT ACTIVE
4. PLASTIC DESIGN(10% CONVERENCE TOLERANCE)

BRACING SIZES(DOUBLE ANGLE, JL)

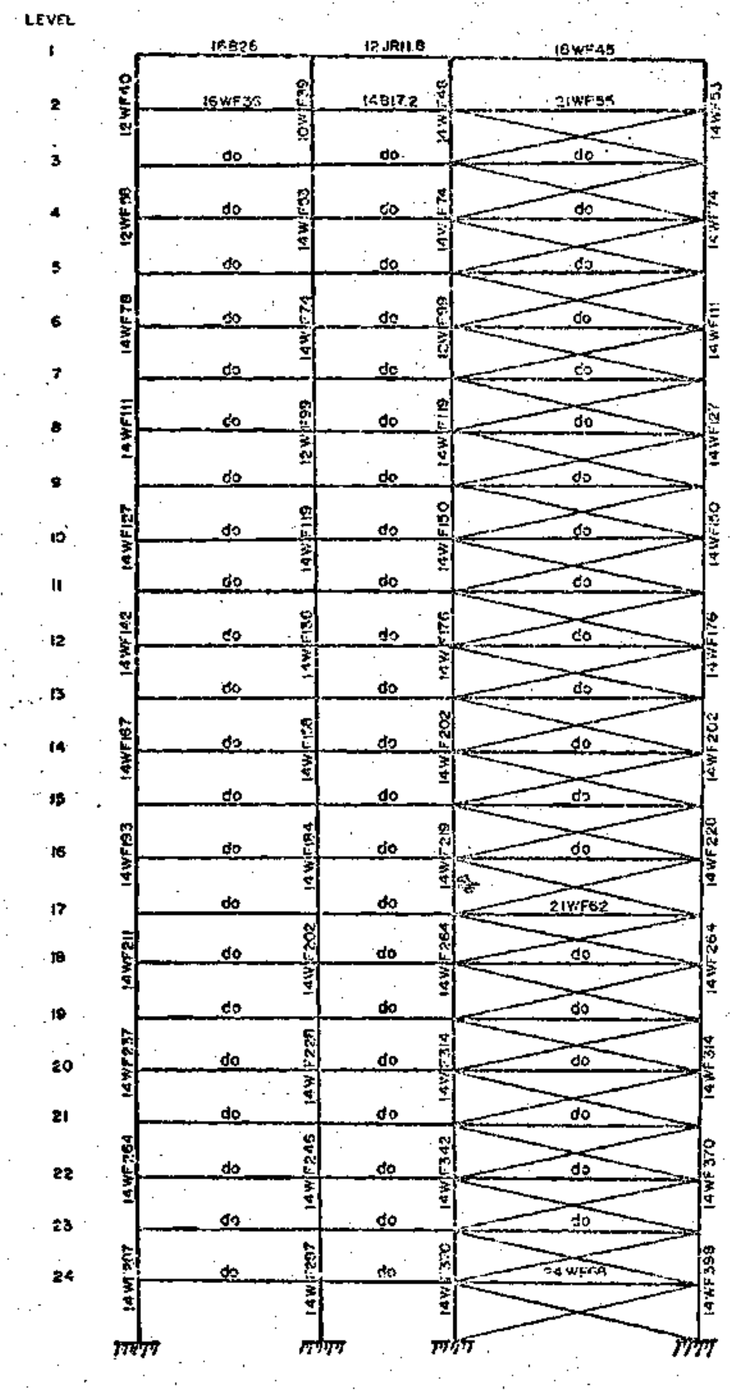
SIZE	STORY	TYPE **
$1 \times 1 \times \frac{1}{8}$	2,3	1,2
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{8}$	4	1,2
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{1}{8}$	5	1,2
$2 \times 2 \times \frac{1}{8}$	6	1,2
$2 \times 2 \times \frac{3}{16}$	7,8	1,2
$3 \times 2 \times \frac{3}{16}$	9,10	1,2
$3 \times 2\frac{1}{2} \times \frac{1}{4}$	11,12,13	1,2
$4 \times 3 \times \frac{1}{4}$	14,15,16	1,2
$3 \times 2\frac{1}{2} \times \frac{3}{8}$	17	1,2
$4 \times 3 \times \frac{5}{16}$	18	1,2
$4 \times 3\frac{1}{2} \times \frac{5}{16}$	19	1,2
$4 \times 3 \times \frac{3}{8}$	20	1,2
$4 \times 3\frac{1}{2} \times \frac{3}{8}$	21	1,2
$4 \times 3 \times \frac{7}{16}$	22	1,2
$4 \times 3 \times \frac{1}{2}$	23,24	1,2

MATERIAL WEIGHTS AND COSTS

MEMBER	WEIGHT
BEAMS	29.31 TONS
COLUMNS	103.27 TONS
BRACING	7.23 TONS
TOTAL WT.	138.82 TONS
TOTAL COST	$ 55,526.05

** TYPE = 1 = TENSION, WIND FROM THE RIGHT
2 = TENSION, WIND FROM THE LEFT

Figure 15. Example Problem C8.1A



DESIGN CONDITIONS

1. MOMENT ACTION PERMITTED
2. BRACING PERMITTED IN BAY 3 ONLY
3. COLUMN ELONGATION AND SHORTENING INCLUDED IN PLASTIC DESIGN P-Δ EFFECT
4. PLASTIC DESIGN (10% CONVERENCE TOLERANCE)

BRACING SIZES (DOUBLE ANGLES, ⅃L)

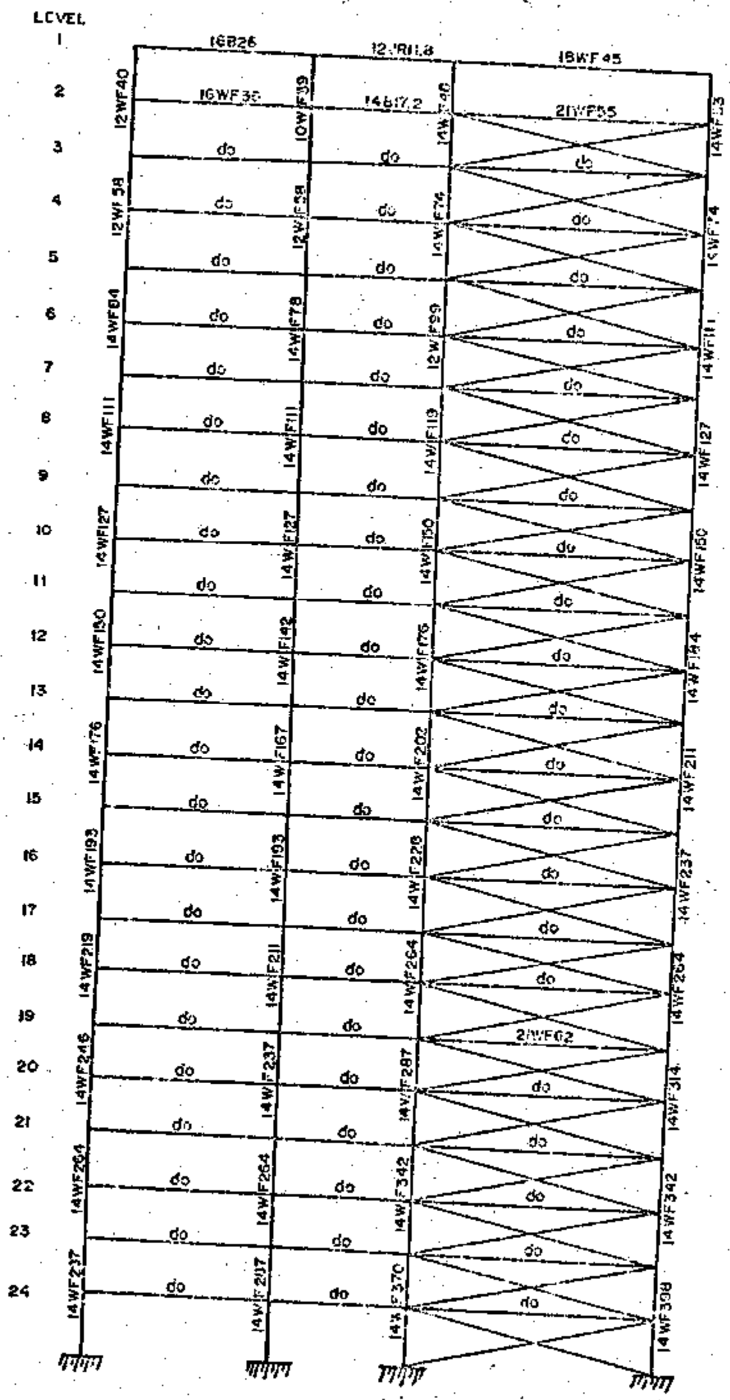
SIZE	STORY	TYPE **
$1 \times 1 \times \frac{1}{8}$	2,3	1,2
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{8}$	4	1,2
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{1}{8}$	5	1,2
$2 \times 2 \times \frac{1}{8}$	6	1,2
$2 \times 2 \times \frac{3}{16}$	7,8	1,2
$3 \times 2 \times \frac{3}{16}$	9	1,2
$3 \times 2\frac{1}{2} \times \frac{1}{4}$	10,12,11,13	1,2
$4 \times 3 \times \frac{1}{4}$	14,15	1,2
$3 \times 2\frac{1}{2} \times \frac{3}{8}$	16,17	1,2
$4 \times 3 \times \frac{5}{16}$	18	1,2
$4 \times 3 \times \frac{3}{8}$	20	1,2
$4 \times 3\frac{1}{2} \times \frac{3}{8}$	19,21	1,2
$4 \times 3 \times \frac{7}{16}$	22	1,2
$4 \times 3 \times \frac{1}{2}$	23,24	1,2

MATERIAL WEIGHTS AND COSTS

MEMBER	WEIGHT
BEAMS	28.42 TONS
COLUMNS	103.01 TONS
BRACING	7.47 TONS
TOTAL WT.	138.90 TONS
TOTAL COST	$ 55,558.70

** TYPE - 1 - TENSION, WIND FROM THE RIGHT
2 - TENSION, WIND FROM THE LEFT

Figure 16. Example Problem C9.1A



DESIGN CONDITIONS

1. MOMENT ACTION PERMITTED
2. BRACING PERMITTED IN BAY 3 ONLY
3. ALL COLUMNS LATERALLY UNBRACED OVER FULL LENGTH
4. PLASTIC DESIGN (5% CONVERGENCE TOLERANCE)

BRACING SIZES (DOUBLE ANGLES, ⅃L)

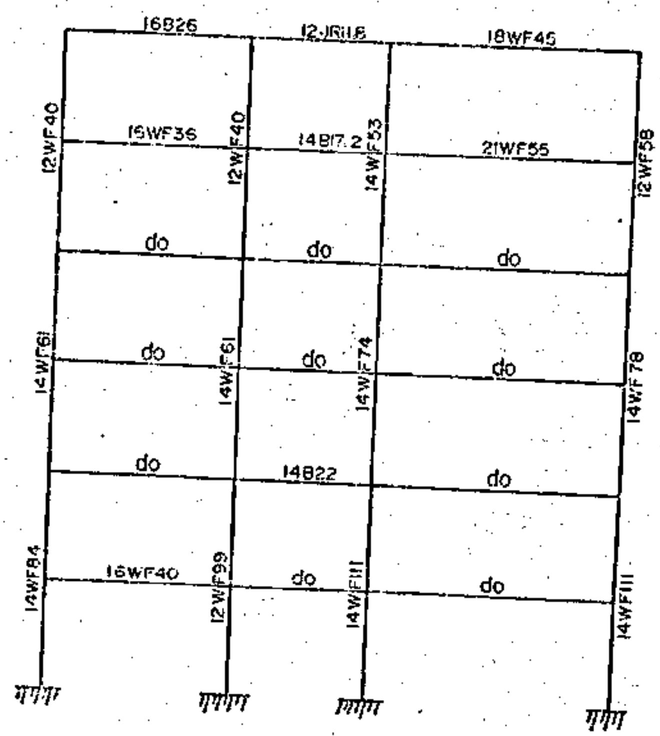
SIZE	STORY	TYPE **
$1 \times 1 \times \frac{1}{8}$	2, 3	1,2
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{8}$	4	1,2
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{1}{8}$	5	1,2
$2 \times 2 \times \frac{1}{8}$	6	1,2
$2 \times 2 \times \frac{3}{16}$	7, 8	1,2
$3 \times 2 \times \frac{3}{16}$	9, 10	1,2
$3 \times 2\frac{1}{2} \times \frac{1}{4}$	11, 12, 13	1,2
$4 \times 3 \times \frac{1}{4}$	14, 15, 16	1,2
$3 \times 2\frac{1}{2} \times \frac{3}{8}$	17	1,2
$4 \times 3 \times \frac{5}{16}$	18	1,2
$4 \times 3\frac{1}{2} \times \frac{5}{16}$	19	1,2
$4 \times 3\frac{1}{2} \times \frac{3}{8}$	20	1,2
$4 \times 3 \times \frac{7}{16}$	21, 22	1,2
$4 \times 3\frac{1}{2} \times \frac{7}{16}$	23	1,2
$6 \times 3\frac{1}{2} \times \frac{3}{8}$	24	1,2

MATERIAL WEIGHTS COSTS

MEMBER	WEIGHT
BEAMS	28.25 TONS
COLUMNS	104.32 TONS
BRACING	7.32 TONS
TOTAL WT.	139.89 TONS
TOTAL COST	$ 55,950.86

** TYPE = 1 = TENSION, WIND FROM THE RIGHT
2 = TENSION, WIND FROM THE LEFT

Figure 17. Example Problem C10.1A

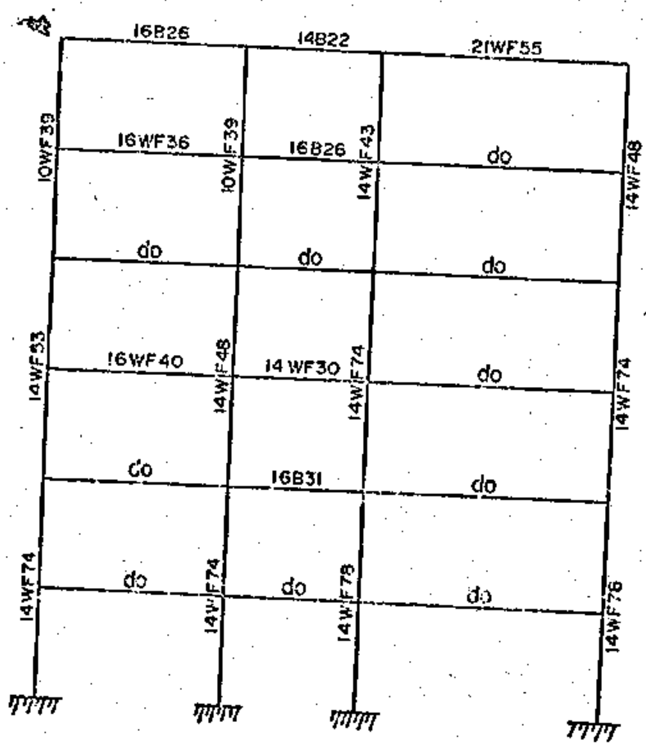


DESIGN CONDITIONS

1. MOMENT ACTION PERMITTED
2. NO BRACING PERMITTED
3. PLASTIC DESIGN (10% CONVERGENCE TOLERANCE)

MATERIAL WEIGHTS AND COSTS

MEMBER	WEIGHT
BEAMS	6.86 TONS
COLUMNS	10.44 TONS
TOTAL WT.	17.30 TONS
TOTAL COST	$ 6,921.56



DESIGN CONDITIONS

1. NO BRACING
2. INITIAL MEMBER PROPERTIES:
   BEAMS TABLE 2
   COLUMNS TABLE 1
3. ELASTIC STRESS DESIGN ($\sigma_{max} \leq \sigma_y$)

MATERIAL WEIGHTS AND COSTS

MEMBER	WEIGHT
BEAMS	7.80 TONS
COLUMNS	8.66 TONS
TOTAL WT.	16.46 TONS
TOTAL COST	$ 6,584.00

Figure 18. Example Problems EX1 and EX2

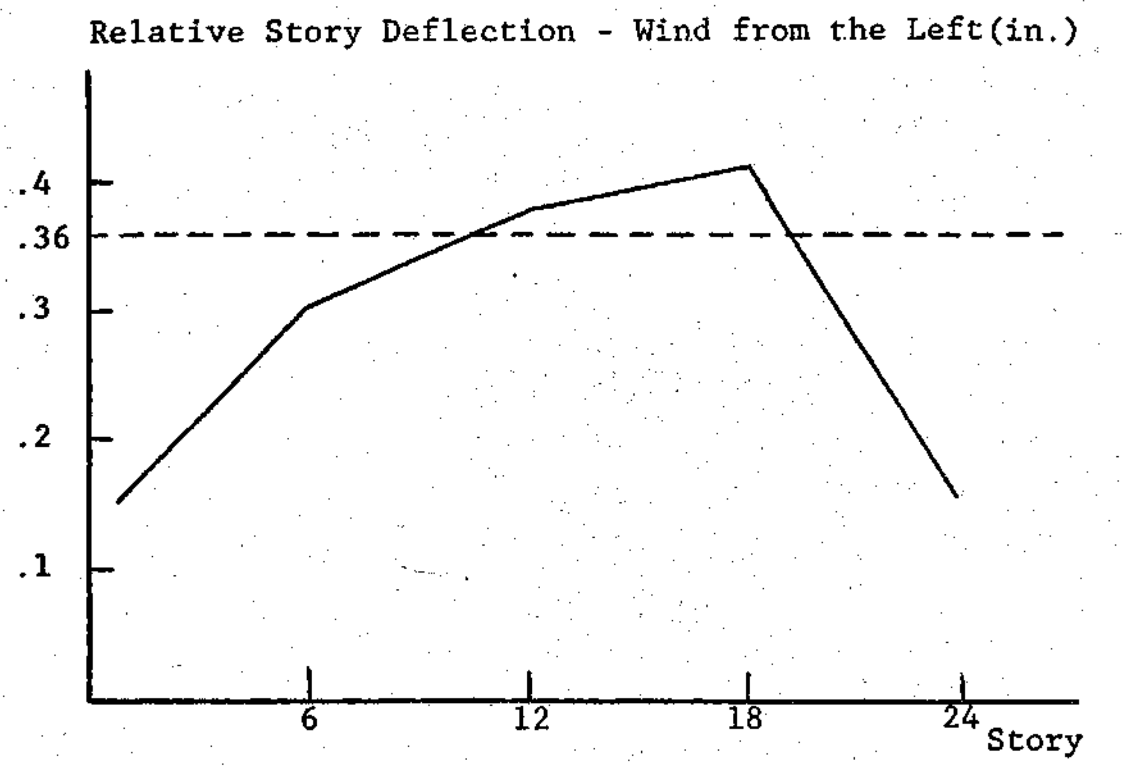
Table 5. Relative Story Deflections - Stiffness Design, Cl.1A

Story	Prior to First Cycle		After First Cycle	
	Wind left	Wind right	Wind left	Wind right
1	.151	.211	.145	.205
2	.190	.283	.181	.275
3	.217	.314	.203	.301
4	.263	.362	.242	.342
5	.277	.386	.250	.359
6	.308	.415	.281	.388
7	.331	.407	.305	.381
8	.356	.431	.326	.402
9	.360	.435	.326	.401
10	.376	.449	.343	.417
11	.370	.442	.342	.415
12	.384	.454	.355	.425
13	.391	.457	.362	.428
14	.390	.454	.360	.423
15	.396	.455	.356	.415
16	.405	.460	.365	.420
17	.399	.448	.360	.409
18	.393	.436	.360	.403
19	.381	.420	.352	.391
20	.374	.406	.348	.379
21	.365	.387	.339	.361
22	.351	.366	.328	.342
23	.308	.311	.288	.291
24	.168	.165	.158.	.155

Story	After Second Cycle	
	Wind left	Wind right
1	.111	.198
2	.143	.259
3	.167	.282
4	.205	.315
5	.20	.318
6	.231	.321
7	.247	.301
8	.266	.308
9	.263	.308
10	.269	.312
11	.250	.301

Table 5. Continued

12	.253	.301
13	.250	.296
14	.249	.293
15	.255	.292
16	.255	.295
17	.244	.287
18	.255	.288
19	.260	.286
20	.264	.289
21	.289	.294
22	.299	.308
23	.273	.278
24	.157	.155



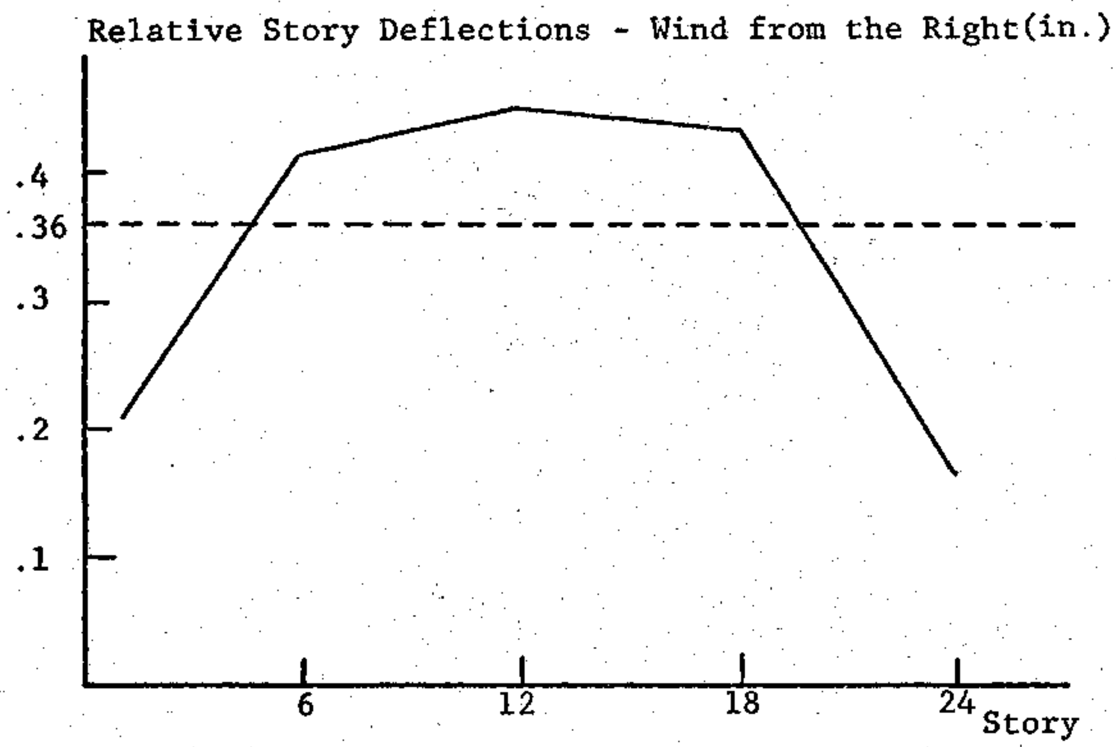


Figure 19. Relative Story Deflections, Elastic Stiffness Design, Prior to First Design Cycle - Example C1.1A.

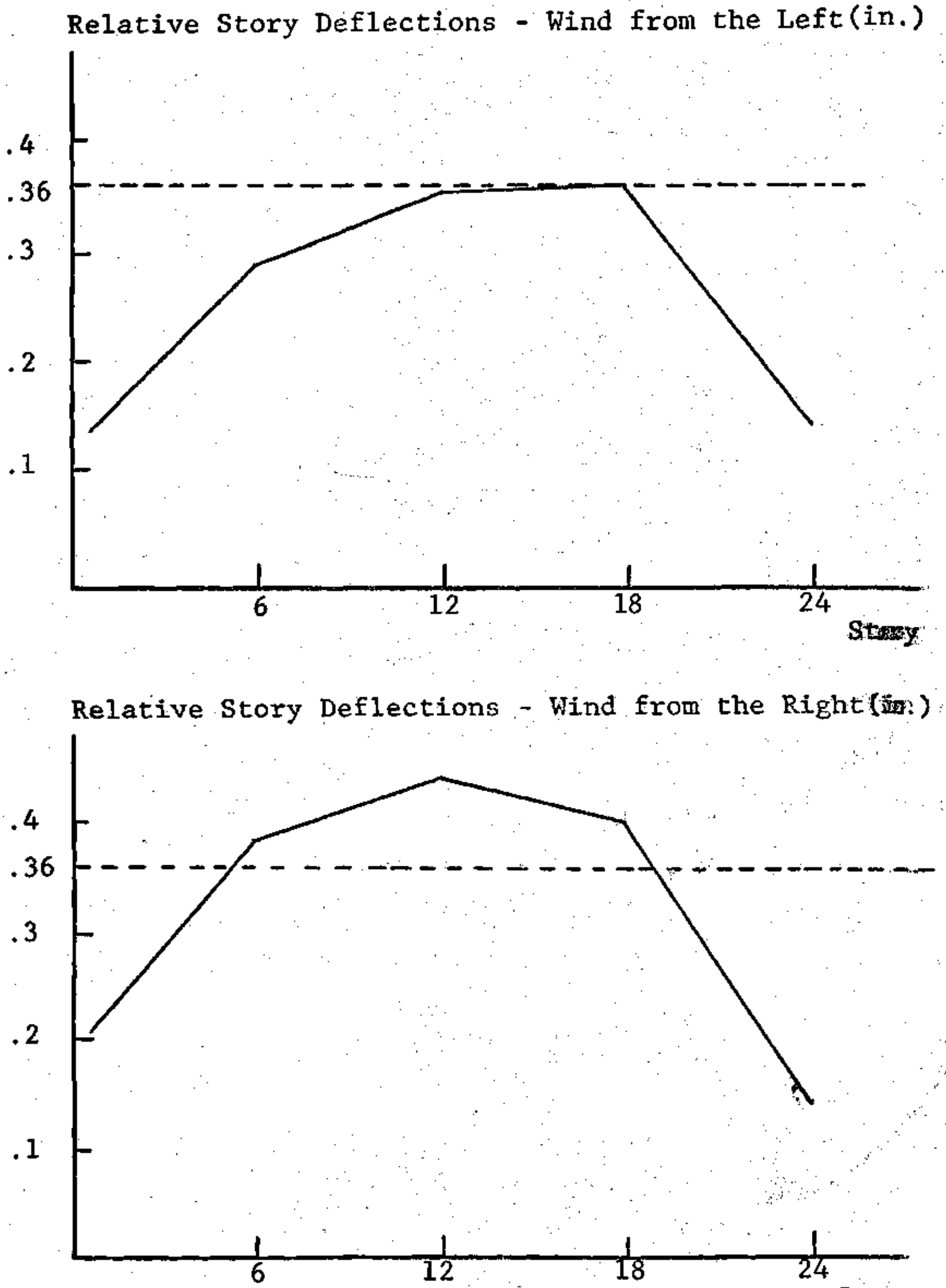
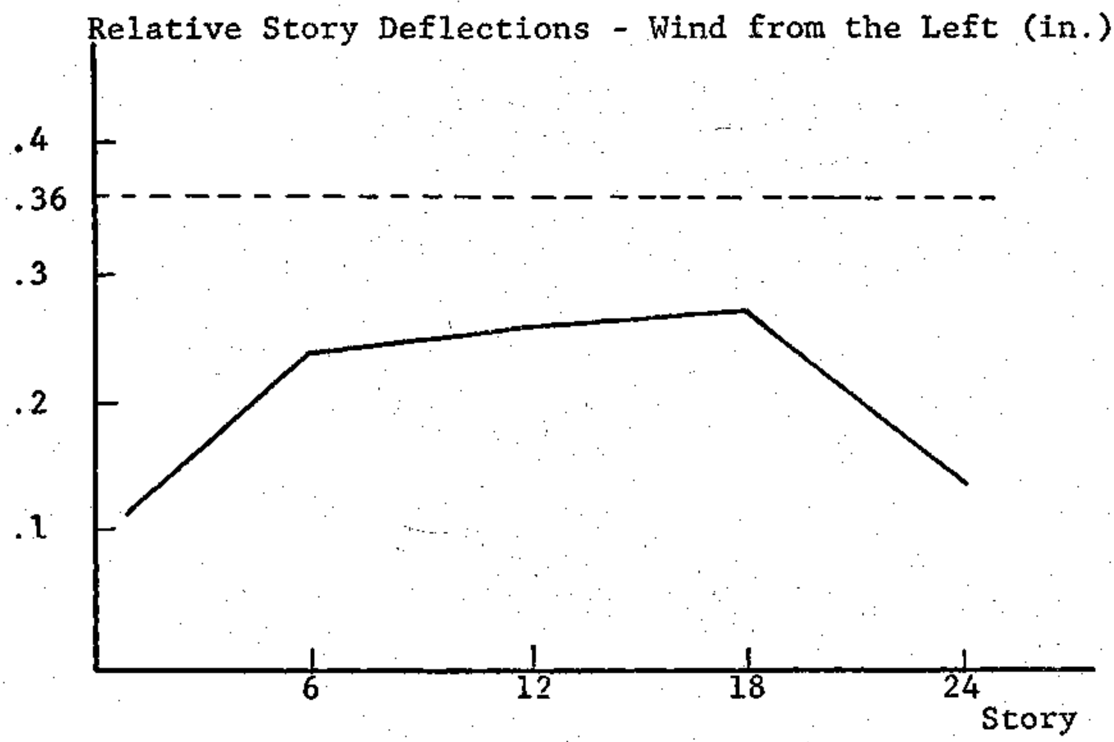


Figure 20. Relative Story Deflections, Elastic Stiffness Design, After First Design Cycle - Example C1.1A.



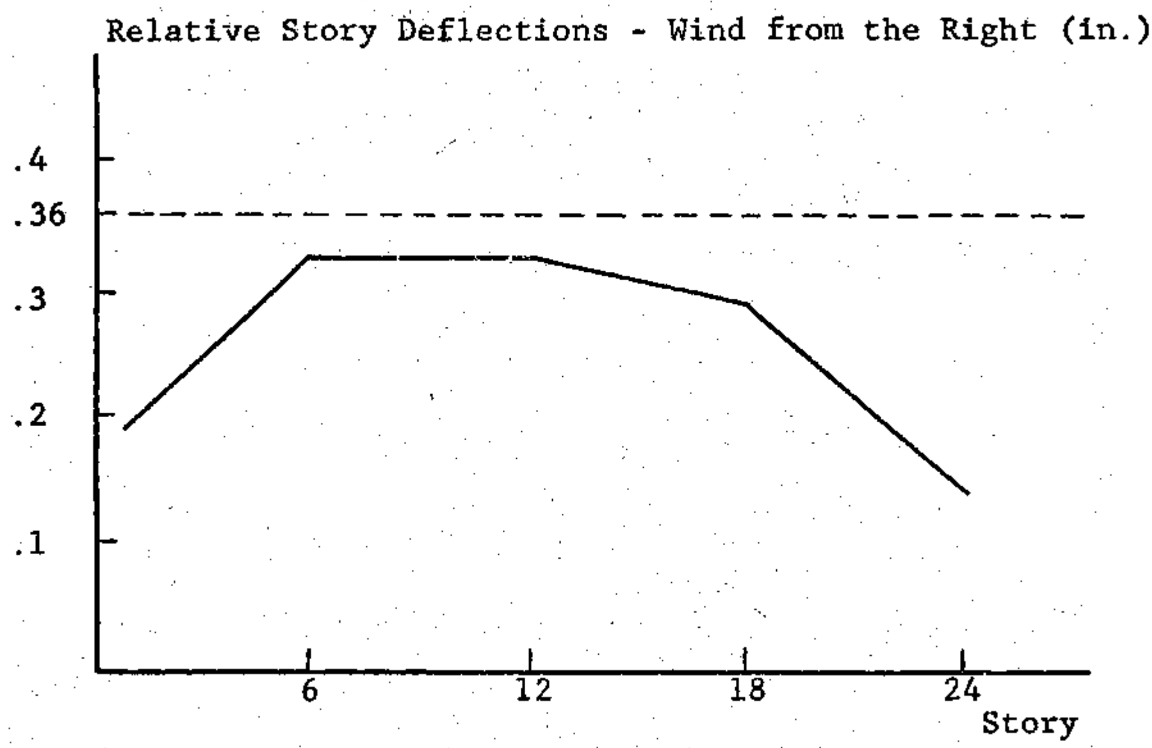


Figure 21. Relative Story Deflections, Elastic Stiffness Design, After Second Design Cycle - Example C1.1A.

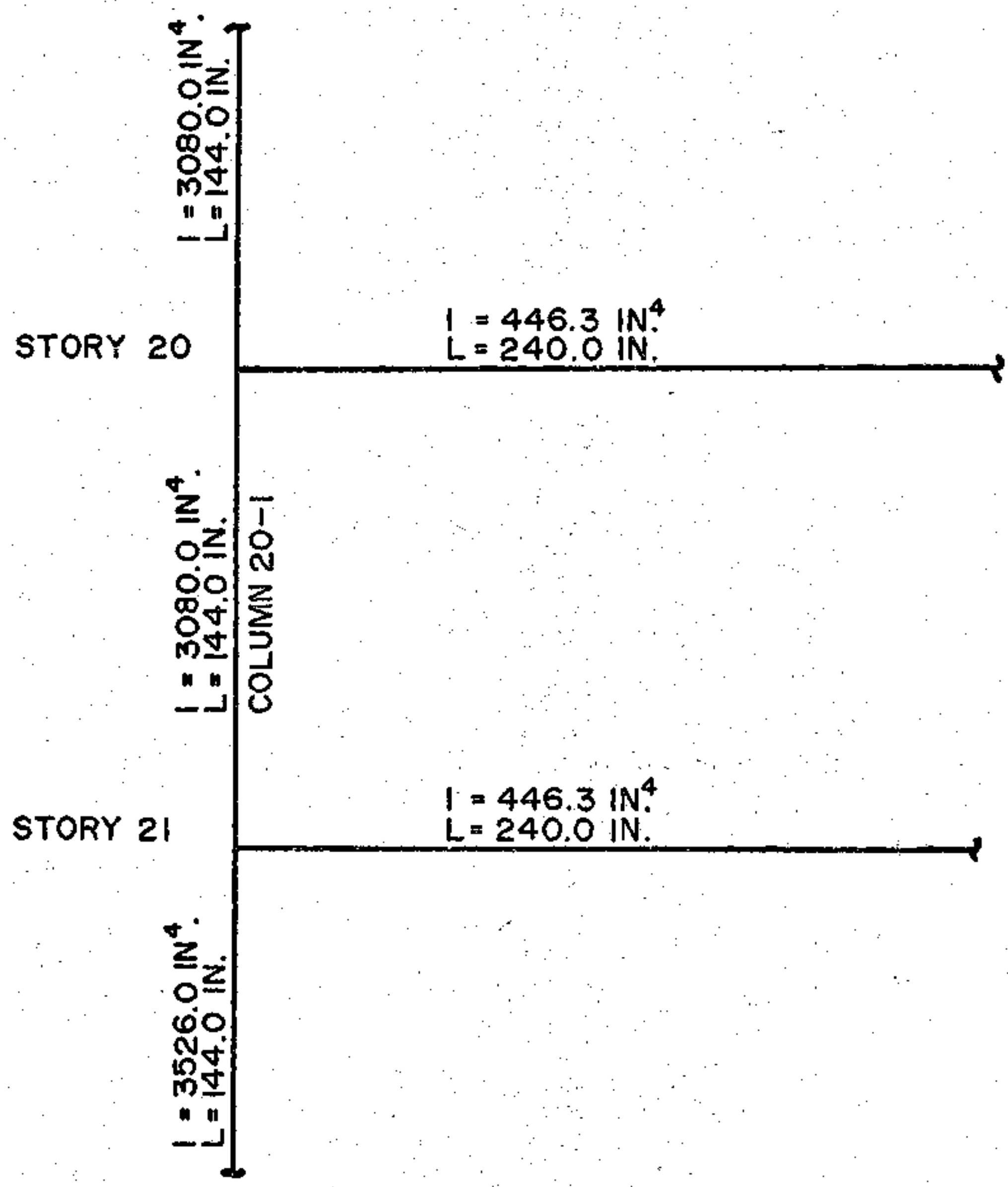


Figure 22. Effective Length of Column 20-1.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The ICES PLADS I computer design system described herein is both an efficient and practical tool for both engineering practice and academic uses.

The efficiency of the system is demonstrated by the fact that execution time for the large 24 story frames averaged about 34 minutes of CPU time in an 80 K word core region. At commercial rates of approximately $1200.00/ CPU hour, the average computer cost of these examples is $680.00 for a complete 24 story frame design including plastic design, elastic stress and elastic stiffness designs. The practicality of the system is demonstrated by the following:

1. INPUT to the system is easily and clearly specified and the design processes are easily controlled by the PLADS Problem Oriented Language (POL).

2. The ICES programming concepts allow problem size to be relatively independent of the computer system. However, the UNIVAC implementation of the ICES basic system seems to be causing unexpected problems such as: (1) for small problems a complete design cannot be executed in a

main core region of less than 65 K words and larger problems require more core; (2) overhead related to the UNIVAC Version 1.1 of the ICES basic system is extensive, detracting from more efficient execution of large design problems.

3. PLADS considers both braced and unbraced frames. The American Institute of Steel Construction has recently released provisions for the design of unbraced frames of any number of stories (2). These provisions state that column effective lengths be considered in column plastic design. PLADS considers this at the user's request and not only is PLADS I the only available computer system to provide a method of rational plastic design for braced frames, it is the only one available for unbraced frame design at a time when the acceptance of such practice is emerging.

4. PLADS automatically considers live load reduction on column axial loads for column design.

5. The weak beam - strong column design constraint is considered at user request.

6. PLADS I allows the user to specify the plastic design P-delta convergence criterion. This is a very important capability since it was discovered that in some difficult-to-predict cases, convergence to a plastic design solution was inhibited because discrete member size changes did not allow a change in the deltas within the specified tolerance.

The author has not compiled enough data on which to base any concrete conclusions regarding this problem; but it was found that this problem occured most often in frames of about 10 stories in height. Therefore, the author recommends that extra care be exercized when determining P-delta convergence criteria for frames with between 8 and 13 stories.

7. Automatic member selection from user provided section tables.

8. Consideration of beam and column depth constraints throughout the design.

9. Automatic determination of the location of bracing elements at the user's request. The results of examples C1.1A through C5.1A demonstrate this capability very effectively. However, some control over the location of bracing should be exercised by the user since the free bracing case may yield unrealistic bracing patterns (example problem C2.1A).

10. Automatic distribution of total required story shear and moment capacity into a story utilizing an heuristic optimization algorithm to minimize steel weight.

11. Automatic cycling of design to account for the P-delta effect. In addition to the effects of beam and column bending and brace elongation, delta for the P-delta effect includes, on user request, the effects of column elongation and shortening. It has been shown that caution

should be exercised when specifying that column elongation and shortening effects be considered since their contribution may be unpredictable, probably due to the arbitrary manner in which an equilibrium force distribution is generated.

12. The supported bent capability is included whereby the frame being considered by PLADS I will be designed to support the additional P-delta effect from adjacent simple framed bents which are designed only to support gravity loads.

13. Automatic redesign to satisfy user-imposed elastic stress constraints.

14. Automatic redesign to satisfy user-imposed elastic lateral deflection constraint utilizing an heuristic optimization algorithm to minimize steel weight. Note that prior to the execution of this particular capability, it is always necessary that maximum elastic stress limits not greater than the yield stress are satisfied for all members in order that elastic behavior at working loads is maintained.

Recommendations

Recommendations for future work in the ICES PLADS I subsystem are as follows:

1. Develop a more flexible loading specification to allow for the specification of more general loading

types such as concentrated loads applied directly to members.

2. Currently, the design system uses an extremely large number of arrays and executes a large number of load modules in the P-delta design process because the complete design process is executed for each and every increment of ultimate story shear in every design cycle. This property of the design system creates an excessive amount of overhead relative to ICES data management. This is undesirable in an ICES environment and improvement may be made by improving the data structure to reduce the number of dynamic arrays and improving the logic so that the design process operates in a more compact manner, reducing the number of modules that need to be repeatedly loaded into core.

3. Extend the design system to include:

(a) A consideration of checkerboard loading patterns;

(b) A consideration of actual deflection of beams constraint;

(c) A consideration of more general bracing types (i.e. k-bracing, etc.);

(d) A consideration of more general loading configurations such as concentrated loads applied at various points along the beams;

(e) A consideration of simple beam connection effects which requires a complete reformation of PLADS I plastic design philosophy;

(f) Automatic compensation for a user-specified P-delta convergence tolerance when discrete member size changes do not result in delta changes within this specified convergence tolerance;

(g) A consideration of section group number in the use of a yield stress in design;

(i) The addition of a cantilever method of distributing lateral shear into a story so that column elongation and shortening effects may be included when approximate lateral deflection analysis is requested independently of plastic design.

4. Reconstruct the output of final elastic stress and stiffness design results to be more efficient. At present, a complete stiffness analysis is executed at the close of elastic stress and stiffness design to provide final stress, force and displacement output. This is unnecessary and inefficient since this output could be generated in the final elastic stiffness and stress design cycle.

5. Extend the system to three-dimensional structures including:

(a) A procedure to distribute lateral loads to the bents of a building according to relative bent stiffness;

(b) A consideration of biaxial column bending;

(c) A formulation of an approximate three-dimensional deflection calculation to include the effects of overall frame torsion.

6. Add a check to the plastic design part for the stability of the frame at factored gravity loads and redesign members if necessary.

7. Also, add to the plastic design part a design check to satisfy the requirement that the axial force in columns in a story where no bracing exists must be less than or equal to 75% of the ultimate axial force, P_y, as per Supplement No. 3, Section 2.3.2, Reference 2.

APPENDIX I

SECTION PROPERTIES OF ROLLED STEEL SHAPES USED IN THE EXAMPLE PROBLEMS

Rolled sections* and their section properties used in the example problems are tabulated in the following Tables 6 to 10.

Table 6 presents the economy beam sections.

Table 7 presents the non-economy beam sections used when beam depth constraints controlled beam sizes.

Table 8 presents the economy column sections. Since column depth constraints were not considered in the design examples, a table of non-economy column sections is not presented.

Table 9 presents the equal leg double angle bracing sections when used.

Table 10 presents the unequal leg double angle bracing sections when used.

*Note that all sections used are taken from the AISC Manual (2).

Table 6. Economy Beam Sections.

SECTION	Wt./Ft. (lb/ft)	AREA (in.^{2})	DEPTH (in.)	MOMENT OF INERTIA I_x (in.^{4})	I_y (in.^{4})	SECTION MODULUS S_x (in.^{3})	PLASTIC MODULUS Z_x (in.^{3})	RADIUS OF GYRATION r_x (in.)	r_y (in.)
6JR4.4	4.4	1.30	6.00	7.3	0.17	2.4	2.8	2.37	0.36
8JR6.5	6.5	1.92	8.00	18.7	0.34	4.7	5.4	3.12	0.42
10JR9	9.0	2.64	10.00	39.0	0.63	7.8	9.2	3.85	0.48
12JR11.8	11.8	3.45	12.00	72.2	0.98	12.0	14.3	4.57	0.53
10B15	15.0	4.40	10.00	68.8	2.79	13.8	16.0	3.95	0.80
12B16.5	16.5	4.86	12.00	105.3	2.79	17.5	20.6	4.65	0.76
14B17.2	17.2	5.05	14.00	147.3	2.65	21.0	24.7	5.40	0.72
14B22	22.0	6.47	13.72	197.4	6.40	28.8	33.0	5.52	0.99
16B26	26.0	7.65	15.65	298.1	8.71	38.1	43.9	6.24	1.07
14WF30	30.0	8.81	13.86	289.6	17.5	41.8	47.1	5.73	1.41
16B31	31.0	9.12	15.84	372.5	11.57	47.0	53.8	6.39	1.13
14WF34	34.0	10.00	14.00	339.2	21.3	48.5	54.5	5.83	1.46
16WF36	36.0	10.59	15.85	446.3	22.1	56.3	63.9	6.49	1.45

Table 6. Continued

SECTION	Wt./Ft. (lb/ft)	AREA (in.^{2})	DEPTH (in.)	MOMENT OF INERTIA I_x (in.^{4})	MOMENT OF INERTIA I_y (in.^{4})	SECTION MODULUS S_x (in.^{3})	PLASTIC MODULUS Z_x (in.^{3})	RADIUS OF GYRATION r_x (in.)	RADIUS OF GYRATION r_y (in.)
16WF40	40.0	11.77	16.00	515.5	26.5	64.4	72.7	6.62	1.50
18WF45	45.0	13.24	17.86	704.5	31.9	78.9	89.6	7.30	1.55
18WF50	50.0	14.71	18.00	800.6	37.2	89.0	100.8	7.38	1.59
21WF55	55.0	16.18	20.80	1140.7	44.0	109.7	125.4	8.40	1.65
21WF62	62.0	18.23	20.99	1326.8	53.1	126.4	144.1	8.53	1.71
24WF68	68.0	20.00	23.71	1814.5	63.8	153.1	175.5	9.53	1.79
24WF76	76.0	22.37	23.91	2096.4	76.5	175.4	200.1	9.68	1.85
27WF84	84.0	24.71	26.69	2824.8	95.7	211.7	243.2	10.69	1.97
27WF94	94.0	27.65	26.91	3266.7	115.1	242.8	277.7	10.87	2.04
30WF99	99.0	29.11	29.64	3988.6	116.9	269.1	312.0	11.70	2.00
30WF108	108.0	31.77	29.82	4461.0	135.1	299.2	345.5	11.85	2.06
30WF116	116.0	34.13	30.00	4919.1	153.2	327.9	377.6	12.00	2.12
33WF118	118.0	34.71	32.86	5886.9	170.3	358.3	414.3	13.02	2.2

Table 6. Continued

SECTION	Wt./Ft. (lb/ft)	AREA (in.^{2})	DEPTH (in.)	MOMENT OF INERTIA I_x (in.^{4})	I_y (in.^{4})	SECTION MODULUS S_x (in.^{3})	PLASTIC MODULUS Z_x (in.^{3})	RADIUS OF GYRATION r_x (in.)	r_y (in.)
33WF130	130.0	38.26	33.10	6699.0	201.4	404.8	466.0	13.23	2.29
36WF135	135.0	39.70	35.55	7796.1	207.1	438.6	509.1	14.01	2.28
36WF150	150.0	44.16	35.84	9012.1	250.4	502.9	579.8	14.29	2.38
36WF160	160.0	47.09	36.00	9738.8	275.4	541.0	623.3	14.38	2.42
36WF170	170.0	49.98	36.16	10470.0	300.6	579.1	666.7	14.47	2.45
36WF182	182.0	53.54	36.32	11281.5	327.7	621.2	716.9	14.52	2.47
36WF194	194.0	57.11	36.48	12103.4	355.4	663.6	767.2	14.56	2.49
36WF230	230.0	67.73	35.88	14988.4	870.9	835.5	942.7	14.88	3.59
36WF245	245.0	72.03	36.06	16092.2	944.7	892.5	1008.0	14.95	3.62
36WF260	260.0	76.56	36.24	17233.8	1020.6	951.1	1076.0	15.00	3.65
36WF280	280.0	82.32	36.50	18819.3	1127.5	1031.2	1167.0	15.12	3.70
36WF300	300.0	88.17	36.72	20290.2	1225.2	1105.1	1255.0	15.17	3.73

Table 7. Non-economy Beam Sections.

SECTION	Wt./Ft. (lb/ft)	AREA (in.^{2})	DEPTH (in.)	MOMENT OF INERTIA I_x (in.^{4})	I_y (in.^{4})	SECTION MODULUS S_x (in.^{3})	PLASTIC MODULUS Z_x (in.^{3})	RADIUS OF GYRATION r_x (in.)	r_y (in.)
12WF45	45.0	13.24	12.06	350.8	50.0	58.2	64.9	5.15	1.94
10WF54	54.0	15.88	10.12	305.7	103.9	60.4	67.0	4.39	2.56
12WF50	50.0	14.71	12.19	394.5	56.4	64.7	72.6	5.18	1.96
10WF72	72.0	21.18	10.50	420.7	141.8	80.1	90.7	4.46	2.59
10WF89	89.0	26.19	10.88	542.4	180.6	99.7	114.4	4.55	2.63
12WF79	79.0	23.22	12.38	663.0	216.4	107.1	119.3	5.34	3.05
18WF60	60.0	17.64	18.25	984.0	47.1	107.8	122.6	7.47	1.63
14WF74	74.0	21.76	14.19	796.8	133.5	112.3	125.6	6.05	2.48
10WF100	100.0	29.43	11.12	625.0	206.6	112.4	130.1	4.61	2.65
18WF64	64.0	18.80	17.87	1045.8	70.3	117.0	131.8	7.46	1.93
14WF78	78.0	22.94	14.06	851.2	206.9	121.1	134.0	6.09	3.00
12WF92	92.0	27.06	12.62	788.9	256.4	125.0	140.2	5.40	3.08
18WF70	70.0	20.56	18.00	1153.9	78.5	128.2	144.7	7.49	1.95

Table 7. Continued

SECTION	Wt./Ft. (lb/ft)	AREA (in.^{2})	DEPTH (in.)	MOMENT OF INERTIA I_x (in.^{4})	MOMENT OF INERTIA I_y (in.^{4})	SECTION MODULUS S_x (in.^{3})	PLASTIC MODULUS Z_x (in.^{3})	RADIUS OF GYRATION r_x (in.)	RADIUS OF GYRATION r_y (in.)
16WF78	78.0	22.92	16.32	1042.6	87.5	127.8	145.5	6.74	1.95
10WF112	112.0	32.92	11.38	718.7	235.4	126.3	147.5	4.67	2.67
12WF99	99.0	29.09	12.75	858.5	278.2	134.7	151.3	5.43	3.09
18WF77	77.0	22.63	18.16	1286.8	88.6	141.7	160.5	7.54	1.98
12WF106	106.0	31.19	12.88	930.7	300.9	144.5	163.4	5.46	3.11
16WF88	88.0	25.87	16.16	1222.6	185.2	151.3	169.0	6.87	2.67
18WF85	85.0	24.97	18.32	1429.9	99.4	156.1	177.6	7.57	2.00
12WF120	120.0	35.31	13.12	1071.7	345.1	163.4	186.4	5.51	3.13
21WF82	82.0	24.10	20.86	1752.4	89.6	168.0	191.6	8.53	1.93
18WF96	96.0	28.22	18.16	1674.7	206.8	184.4	206.0	7.70	2.71
18WF105	105.0	30.86	18.32	1852.5	231.0	202.2	226.5	7.75	2.73
18WF114	114.0	33.51	18.48	2033.8	255.6	220.1	247.9	7.79	2.76
21WF112	112.0	32.93	21.0	2620.6	289.7	249.6	278.0	8.92	2.96

Table 7. Continued

SECTION	Wt./Ft. (lb/ft)	AREA (in.^{2})	DEPTH (in.)	MOMENT OF INERTIA I_x (in.^{4})	I_y (in.^{4})	SECTION MODULUS S_x (in.^{3})	PLASTIC MODULUS Z_x (in.^{3})	RADIUS OF GYRATION r_x (in.)	r_y (in.)
14WF158	158.0	46.47	15.00	1900.6	745.0	253.4	286.3	6.40	4.00
14WF167	167.0	49.09	15.12	2020.8	790.2	267.3	302.9	6.42	4.01
24WF110	110.0	32.36	24.16	3315.0	229.1	274.4	307.7	10.12	2.66
12WF190	190.0	55.86	14.38	1892.5	589.7	263.2	311.5	5.82	3.25
21WF127	127.0	37.34	21.24	3017.2	338.6	284.1	317.8	8.99	3.01
24WF120	120.0	35.29	24.31	3635.3	254.0	299.1	336.6	10.15	2.68
21WF142	142.0	41.76	21.46	3403.1	385.9	317.2	357.0	9.03	3.04
14WF202	202.0	59.39	15.63	2538.8	979.7	324.9	373.6	6.54	4.06
24WF145	145.0	42.62	24.49	4561.0	434.3	372.5	416.0	10.34	3.19
24WF160	160.0	47.04	24.72	5110.3	492.6	413.5	463.7	10.45	3.23
14WF264	264.0	77.63	16.50	3526.0	1331.2	427.4	502.4	6.74	4.14
27WF160	160.0	47.04	27.08	6018.6	458.0	444.5	504.3	11.31	3.12
14WF287	287.0	84.37	16.81	3912.1	1466.5	465.5	551.6	6.81	4.17

Table 7. Continued

SECTION	Wt./Ft. (lb/ft)	AREA (in.^{2})	DEPTH (in.)	MOMENT OF INERTIA I_x (in.^{4})	MOMENT OF INERTIA I_y (in.^{4})	SECTION MODULUS S_x (in.^{3})	PLASTIC MODULUS Z_x (in.^{3})	RADIUS OF GYRATION r_x (in.)	RADIUS OF GYRATION r_y (in.)
27WF177	177.0	52.10	27.31	6728.6	518.9	492.8	556.9	11.36	3.16
33WF152	152.0	44.71	33.50	8147.6	256.1	486.4	558.3	13.36	2.39
30WF172	172.0	50.65	29.88	7891.5	550.1	528.2	593.0	12.48	3.30
30WF190	190.0	55.90	30.12	8825.9	624.6	586.1	659.6	12.57	3.34
30WF210	210.0	61.78	30.38	9872.4	707.9	649.9	733.9	12.64	3.38
14WF398	398.0	116.98	18.31	6013.7	2169.7	656.9	803.0	7.17	4.31
33WF240	240.0	70.52	33.50	13585.1	874.3	811.1	918.2	13.88	3.52
36WF230	230.0	67.73	35.88	14988.4	870.9	835.5	942.7	14.88	3.59
36WF280	280.0	82.32	36.50	18819.3	1127.5	1031.2	1167.0	15.12	3.70
36WF300	300.0	88.17	36.72	20290.2	1225.2	1105.1	1255.0	15.17	3.73

Table 8. Economy Column Sections.

SECTION	Wt./Ft. (lb/ft)	AREA (in.^{2})	DEPTH (in.)	MOMENT OF INERTIA I_x (in.^{4})	MOMENT OF INERTIA I_y (in.^{4})	SECTION MODULUS S_x (in.^{3})	PLASTIC MODULUS Z_x (in.^{3})	RADIUS OF GYRATION r_x (in.)	RADIUS OF GYRATION r_y (in.)
6WF20	20.0	5.90	6.20	41.7	13.3	13.4	15.0	2.66	1.50
8WF24	24.0	7.06	7.93	82.5	18.2	20.8	23.1	3.42	1.61
8WF28	28.0	8.23	8.06	97.8	21.6	24.3	27.1	3.45	1.62
8WF31	31.0	9.12	8.00	109.7	37.0	27.4	30.9	3.47	2.01
8WF35	35.0	10.30	8.12	126.5	42.5	31.1	34.7	3.50	2.03
10WF39	39.0	11.48	9.94	209.7	44.9	42.2	47.0	4.27	1.98
12WF40	40.0	11.77	11.94	310.1	44.1	51.9	57.6	5.13	1.94
14WF43	43.0	12.65	13.68	429.0	45.1	62.7	69.7	5.82	1.89
14WF48	48.0	14.11	13.81	484.9	51.3	70.2	78.5	5.86	1.91
14WF53	53.0	15.59	13.94	542.1	57.5	77.8	87.1	5.90	1.92
12WF58	58.0	17.06	12.19	476.1	107.4	78.1	86.5	5.28	2.51
14WF61	61.0	17.94	13.91	641.5	107.3	92.2	102.4	5.98	2.45

Table 8. Continued

SECTION	Wt./Ft. (lb/ft)	AREA (in.^{2})	DEPTH (in.)	MOMENT OF INERTIA I_x (in.^{4})	I_y (in.^{4})	SECTION MODULUS S_x (in.^{3})	PLASTIC MODULUS Z_x (in.^{3})	RADIUS OF GYRATION r_x (in.)	r_x (in.)
14WF74	74.0	21.76	14.19	796.8	133.5	112.3	125.6	6.05	2.48
14WF78	78.0	22.94	14.06	851.2	206.9	121.1	134.0	6.09	3.00
12WF79	79.0	23.22	12.38	663.0	216.4	107.1	119.3	5.34	3.05
14WF84	84.0	24.71	14.18	928.4	225.5	130.9	145.4	6.13	3.02
12WF99	99.0	29.09	12.75	858.5	278.2	134.7	151.8	5.43	3.09
14WF111	111.0	32.65	14.37	1266.5	454.9	176.3	196.0	6.23	3.73
14WF119	119.0	34.99	14.50	1373.1	491.8	189.4	210.9	6.26	3.75
14WF127	127.0	37.33	14.62	1476.7	527.6	202.0	225.9	6.29	3.76
14WF136	136.0	39.98	14.75	1593.0	567.7	216.0	242.7	6.31	3.77
14WF142	142.0	41.85	14.75	1672.2	660.1	226.7	254.8	6.32	3.97
14WF150	150.0	44.08	14.88	1786.9	702.5	240.2	270.2	6.37	3.99
14WF158	158.0	46.47	15.00	1900.6	745.0	253.4	286.3	6.40	4.00
14WF167	167.0	49.09	15.12	2020.8	790.2	267.3	302.9	6.42	4.01
14WF176	176.0	51.73	15.25	2149.6	837.9	281.9	321.3	6.45	4.02

Table 8. Continued

SECTION	Wt./Ft. (lb/ft)	AREA (in.^{2})	DEPTH (in.)	MOMENT OF INERTIA I_x (in.^{4})	MOMENT OF INERTIA I_y (in.^{4})	SECTION MODULUS S_x (in.^{3})	PLASTIC MODULUS Z_x (in.^{3})	RADIUS OF GYRATION r_x (in.)	RADIUS OF GYRATION r_y (in.)
14WF184	184.0	54.07	15.38	2274.8	882.7	295.8	337.5	6.49	4.04
14WF193	193.0	56.73	15.50	2402.4	930.1	310.0	355.1	6.51	4.05
14WF202	202.0	59.39	15.63	2538.8	979.7	324.9	373.6	6.54	4.06
14WF211	211.0	62.07	15.75	2671.4	1028.6	339.2	391.7	6.56	4.07
14WF219	219.0	64.36	15.87	2798.2	1073.2	352.6	408.0	6.59	4.08
14WF228	228.0	67.06	16.00	2942.4	1124.8	367.8	427.2	6.62	4.10
14WF237	237.0	69.69	16.12	3080.9	1174.8	382.2	445.4	6.65	4.11
14WF246	246.0	72.33	16.25	3228.9	1226.6	397.4	464.5	6.68	4.12
14WF264	264.0	77.63	16.50	3526.0	1331.2	427.4	502.4	6.74	4.14
14WF287	287.0	84.37	16.81	3912.1	1466.5	465.5	551.6	6.81	4.17
14WF314	314.0	92.30	17.19	4399.4	1631.4	511.9	611.5	6.90	4.20

Table 8. Continued

SECTION	Wt./Ft. (lb/ft)	AREA (in.^{2})	DEPTH (in.)	MOMENT OF INERTIA I_x (in.^{4})	I_y (in.^{4})	SECTION MODULUS S_x (in.^{3})	PLASTIC MODULUS Z_x (in.^{3})	RADIUS OF GYRATION r_x (in.)	r_y (in.)
14WF320	320.0	94.12	16.81	4141.7	1635.1	492.8	592.2	6.63	4.17
14WF342	342.0	100.59	17.56	4911.5	1806.9	559.4	673.0	6.99	4.24
14WF370	370.0	108.78	17.94	5454.2	1986.0	608.1	737.3	7.08	4.27
14WF398	398.0	116.98	18.31	6013.7	2169.7	656.9	803.0	7.17	4.31
14WF426	426.0	125.25	18.69	6610.3	2359.5	707.4	869.3	7.26	4.34
14WF455	455.0	133.73	19.05	7214.9	2561.2	757.5	986.0	7.35	4.38
14WF500	500.0	146.95	19.63	8234.1	2882.7	839.1	1099.0	7.48	4.43
14WF550	550.0	161.75	20.26	9443.1	3256.7	932.2	1241.0	7.64	4.49
14WF605	605.0	177.85	20.94	10842.3	3680.9	1035.7	1403.0	7.81	4.55
14WF665	665.0	195.51	21.67	12477.7	4166.2	1151.7	1567.0	7.99	4.62
14WF730	730.0	214.65	22.44	14371.4	4716.8	1280.6	1770.0	8.18	4.69

Table 9. Equal Leg Double Angle Bracing Sections.

AISC DESIGNATION	SECTION NAME INPUT	Wt./ft. (lb./ft.)	AREA (in^2)
$1x1x\frac{1}{8}$	1EAN1.6	1.6	.47
$1\frac{1}{4}x1\frac{1}{4}x\frac{1}{8}$	1EAN2.02	2.0	.59
$1\frac{1}{2}x1\frac{1}{2}x\frac{1}{8}$	1EAN2.46	2.5	.72
$1\frac{3}{4}x1\frac{3}{4}x\frac{1}{8}$	1EAN2.88	2.9	.84
$2x2x\frac{1}{8}$	2EAN3.3	3.3	.96
$2x2x\frac{3}{16}$	2EAN4.88	4.9	1.43

Table 10. Unequal Leg Double Angle Bracing Sections.

AISC DESIGNATION	SECTION NAME INPUT	Wt./Ft. (lb./ft.)	AREA (in.^{2})
$3x2x\frac{3}{16}$	3UAN6.1	6.1	1.80
$3x2\frac{1}{2}x\frac{1}{4}$	3UAN9.0	9.0	2.62
$4x3x\frac{1}{4}$	4UAN11.6	11.6	3.38
$3x2\frac{1}{2}x\frac{3}{8}$	3UAN13.2	13.2	3.84
$4x3x\frac{5}{16}$	4UAN14.4	14.4	4.18
$4x3\frac{1}{2}x\frac{5}{16}$	4UAN15.4	15.4	4.50
$4x3x\frac{3}{8}$	4UAN17.0	17.0	4.96
$4x3\frac{1}{2}x\frac{3}{8}$	4UAN18.2	18.2	5.34
$4x3x\frac{7}{16}$	4UAN19.6	19.6	5.74
$4x3\frac{1}{2}x\frac{7}{16}$	4UAN21.2	21.2	6.18
$4x3x\frac{1}{2}$	4UAN22.2	22.2	6.50
$6x3\frac{1}{2}x\frac{3}{8}$	6UAN23.4	23.4	6.84
$6x4x\frac{3}{8}$	6UAN24.6	24.6	7.22
$5x3x\frac{1}{2}$	5UAN25.6	25.6	7.50
$5x3\frac{1}{2}x\frac{1}{2}$	5UAN27.2	27.2	8.00

Table 10. Continued

AISC DESIGNATION	SECTION NAME INPUT	Wt./Ft. (lb./ft.)	AREA (in.^{2})
$6 \times 4 \times \frac{7}{16}$	6UAN28.6	28.6	8.36
$7 \times 4 \times \frac{7}{16}$	7UAN31.6	31.6	9.24
$8 \times 4 \times \frac{7}{16}$	8UAN34.4	34.4	10.12
$8 \times 4 \times \frac{1}{2}$	8UAN39.2	39.2	11.50
$8 \times 4 \times \frac{3}{4}$	8UAN57.4	57.4	16.88

APPENDIX II

SAMPLE OF ICES PLADS I OUTPUT

This section presents a sample of typical ICES PLADS I output exemplified by the final design and analysis output of a 3 story, 3 bay example problem.

```
PLADS     $ 3 STORY, 3 BAY BRACED FRAME EXAMPLE.

          *********************************************
          *                                           *
          *                                           *
          *              ICES PLADS-I                 *
          *        THE PLASTIC DESIGN SYSTEM          *
          *                                           *
          *                                           *
          *   CIVIL ENGINEERING SYSTEMS LABORATORY    *
          *       SCHOOL OF CIVIL ENGINEERING         *
          *     GEORGIA INSTITUTE OF TECHNOLOGY       *
          *            ATLANTA, GEORGIA               *
          *            V1M0 SEPT. 1974                *
          *                                           *
          *********************************************

//////////////////////////////////////////////////////////////////////
EXCEPT FOR SECTION TABLE, FORCE INPUT UNITS MUST BE IN KIPS.
EXCEPT FOR SECTION TABLE, LENGTH INPUT UNITS MUST BE IN INCHES.
COST INPUT UNITS MUST BE IN CENTS/LB.
SECTION TABLE REQUIRES LENGTH INPUT UNITS TO BE FEET.
SECTION TABLE REQUIRES FORCE INPUT UNITS TO BE IN POUNDS.

SIGN CONVENTION --
    POSITIVE AXIAL FORCE IS COMPRESSION
    POSITIVE END MOMENT IS CLOCKWISE
    POSITIVE BEAM CENTER MOMENT PRODUCES POSITIVE CURVATURE
    IN THE RIGHT-HANDED ORTHOGONAL COORDINATE SYSTEM
//////////////////////////////////////////////////////////////////////
$
$ GEOMETRIC DATA.
$
NUMBER OF STORIES 3
NUMBER OF BAYS 3
STORY HEIGHTS ALL 144.0
BAY LENGTHS
    1 LENGTH 240.0
    2 LENGTH 144.0
    3 LENGTH 336.0
$
$ SECTION DESIGN TABLE DATA.
```

```
$
SECTION BEAM ECONOMY 38
SECTIONS BEAM TOTAL NUMBER 87
     *****  87 BEAM SECTIONS HAVE BEEN READ *****

SECTIONS COLUMN ECONOMY 48
SECTIONS COLUMN TOTAL NUMBER 48
     ***** 48 COLUMN SECTIONS HAVE BEEN READ *****

SECTIONS BRACING 26
     ***** 26 BRACING SECTIONS HAVE BEEN READ *****

$
$ LOADING CONDITION DATA,
$
LOAD FACTORS F1 1.7  F2 1.3
LOADING LATERAL STORY 1 @ 4.8
LOADING LATERAL STORIES 2, 3 @ 5.76
LOADING UNIFORM
     STORY 1 BEAMS ALL DL 0.19 LL 0.06
     STORIES 2,3 BEAM 1 DL 0.24 LL 0.123333
     STORIES 2,3 BEAM 2 DL 0.24 LL 0.154167
     STORIES 2,3 BEAM 3 DL 0.24 LL 0.098333
LOADING CONCENTRATED
     STORY 1 JOINTS 1,4 DL 15.7 LL 0.00
     STORY 1 JOINTS 2,3 DL 7.9 LL 0.00
     STORIES 2,3 JOINTS 1,4 DL 32.0 LL 0.00
     STORIES 2,3 JOINTS 2,3 DL 7.5 LL 0.00
LIVE LOAD REDUCTION FACTORS
     STORY 1 COLUMNS ALL 0.00
     STORY 2 COLUMN 1 0.192
     STORY 2 COLUMN 2 0.307
```

```
STORY 2 COLUMN 3 0.304
STORY 2 COLUMN 4 0.269
STORY 3 COLUMN 1 0.384
STORY 3 COLUMNS 2,3,4 0.509
SUPPORTED GRAVITY LOADS FOR PDELTA EFFECT
STORIES ALL JOINTS ALL DL 42.5 LL 15.85
$
$ MEMBER MATERIAL PROPERTIES,
$
YIELD STRESS CONFIGURATION
STORIES ALL BEAMS ALL FY 36.0
STORIES ALL COLUMNS ALL FY 36.0
STORIES ALL BAY BRACING ALL FY 36.0
MATERIAL UNIT PRICES
STORIES ALL BEAMS ALL COST 20.0
STORIES ALL COLUMNS ALL COST 20.0
STORIES ALL BAY BRACING ALL COST 20.0
$
$ DESIGN CONSTRAINTS,
$
MAXIMUM PERMISSIBLE ELASTIC STRESS AT WORKING LOADS
STORIES ALL BEAMS ALL F 36.0
STORIES ALL COLUMNS ALL F 36.0
$ MAXIMUM STRESS FOR BRACING ASSUMED YIELD STRESS,
MAXIMUM PERMISSIBLE RELATIVE DEFLECTION AT WORKING LOADS
STORIES ALL DELTA 0.24
PANEL ULTIMATE SHEAR RESISTANCE
STORIES ALL PANEL 3 BOTH MOMENT AND TRUSS
STORIES ALL PANELS 1,2 MOMENT
PDELTA COMPUTATION FOR COLUMN ELONGATION AND SHORTENING YES
TOLERANCE FOR PDELTA CONVERGENCE 0.075
```

EFFECTIVE LENGTH COMPUTATION FOR COLUMN DESIGN YES

$

$ DESIGN AND OUTPUT DIRECTIVES.

$

PRINT PROBLEM INPUT DATA

****

LISTING OF INPUT DATA

****

NUMBER OF BAYS = 3
NUMBER OF STORIES = 3

BAY LENGTHS

BAY	LENGTH
1	240,000
2	144,000
3	336,000

STORY HEIGHTS

STORY	HEIGHT
1	144,000
2	144,000
3	144,000

LOAD FACTOR FOR GRAVITY LOAD CONDITION = 1,70
LOAD FACTOR FOR THE COMBINATION GRAVITY PLUS WIND LOAD CONDITION = 1,30

UNFACTORED UNIFORM DEAD AND LIVE LOADS APPLIED TO BEAMS

STORY	BEAM	DEAD LOAD	LIVE LOAD
1	1	.190	.060
2	1	.240	.123
3	1	.240	.123
1	2	.190	.060
2	2	.240	.154

3	2	.240	.154
1	3	.190	.060
2	3	.240	.098
3	3	.240	.098

UNFACTORED CONCENTRATED DEAD AND LIVE LOADS APPLIED TO JOINTS

STORY	JOINT	DEAD LOAD	LIVE LOAD
1	1	15,700	.000
2	1	32,000	.000
3	1	32,000	.000
1	2	7,500	.000
2	2	7,500	.000
3	2	7,500	.000
1	3	7,500	.000
2	3	7,500	.000
3	3	7,500	.000
1	4	15,700	.000
2	4	32,000	.000
3	4	32,000	.000

SUPPORTED GRAVITY JOINT LOADS FOR PDELTA EFFECT

STORY	JOINT	DEAD LOAD	LIVE LOAD
1	1	42,500	15,850
2	1	42,500	15,850
3	1	42,500	15,850
1	2	42,500	15,850
2	2	42,500	15,850
3	2	42,500	15,850
1	3	42,500	15,850
2	3	42,500	15,850
3	3	42,500	15,850
1	4	42,500	15,850
2	4	42,500	15,850
3	4	42,500	15,850

LATERAL UNFACTORED WIND LOAD APPLIED TO STORY LEVELS

STORY	LATERAL LOAD
1	4,800
2	5,760
3	5,760

LIVE LOAD REDUCTION COEFFICIENTS FOR COLUMNS

STORY	COLUMN	RED. COEF.
1	1	.000

2	1	.269
3	1	.304

INITIALLY ASSUMED RELATIVE STORY DEFLECTION AT THE ULTIMATE LOAD

STORY	DEFLECTION
1	.000
2	.000
3	.000

MAXIMUM PERMISSIBLE ELASTIC RELATIVE STORY DEFLECTION FOR UNFACTORED LOADS

STORY	DEFLECTION
1	.240
2	.240
3	.240

STEEL YIELD STRESS FOR BEAMS

STORY	BEAM	YIELD STRESS
1	1	36,000
2	1	36,000
3	1	36,000
1	2	36,000
2	2	36,000
3	2	36,000
1	3	36,000
2	3	36,000
3	3	36,000

STEEL YIELD STRESS FOR COLUMNS

STORY	COLUMN	YIELD STRESS
1	1	36,000
2	1	36,000
3	1	36,000
1	2	36,000
2	2	36,000
3	2	36,000
1	3	36,000
2	3	36,000
3	3	36,000
1	4	36,000
2	4	36,000
3	4	36,000

YIELD STRESS OF BRACING ELEMENTS

STORY	BAY	YIELD STRESS
1	1	36,000
2	1	36,000
3	1	36,000
1	2	36,000
2	2	36,000
3	2	36,000
1	3	36,000
2	3	36,000
3	3	36,000

UNIT MATERIAL PRICES OF BEAMS

STORY	BEAM	UNIT PRICE
1	1	20,000
2	1	20,000
3	1	20,000
1	2	20,000
2	2	20,000
3	2	20,000
1	3	20,000
2	3	20,000
3	3	20,000

UNIT MATERIAL PRICES OF COLUMNS

STORY	COLUMN	UNIT PRICE
1	1	20,000
2	1	20,000
3	1	20,000
1	2	20,000
2	2	20,000
3	2	20,000
1	3	20,000
2	3	20,000
3	3	20,000
1	4	20,000
2	4	20,000
3	4	20,000

UNIT MATERIAL PRICES OF BRACING

STORY	BAY	UNIT PRICE
1	1	20,000
2	1	20,000
3	1	20,000
1	2	20,000
2	2	20,000

3	2	20.000
1	3	20.000
2	3	20.000
3	3	20.000

MAXIMUM LATERALLY UNSUPPORTED LENGTHS OF BEAMS

STORY	BEAM	UNSUPPORTED LENGTH
1	1	48.000
2	1	48.000
3	1	48.000
1	2	48.000
2	2	48.000
3	2	48.000
1	3	48.000
2	3	48.000
3	3	48.000

MAXIMUM LATERALLY UNSUPPORTED LENGTHS OF COLUMNS

STORY	COLUMN	UNSUPPORTED LENGTH
1	1	144.000
2	1	144.000
3	1	144.000
1	2	144.000
2	2	144.000
3	2	144.000
1	3	144.000
2	3	144.000
3	3	144.000
1	4	144.000
2	4	144.000
3	4	144.000

MAXIMUM PERMISSIBLE BEAM DEPTHS

STORY	BEAM	MAXIMUM DEPTH
1	1	10000.000
2	1	10000.000
3	1	10000.000
1	2	10000.000
2	2	10000.000
3	2	10000.000
1	3	10000.000
2	3	10000.000
3	3	10000.000

MAXIMUM PERMISSIBLE COLUMN DEPTHS

STORY	COLUMN	MAXIMUM DEPTH
1	1	10000,000
2	1	10000,000
3	1	10000,000
1	2	10000,000
2	2	10000,000
3	2	10000,000
1	3	10000,000
2	3	10000,000
3	3	10000,000
1	4	10000,000
2	4	10000,000
3	4	10000,000

MAXIMUM PERMISSIBLE ELASTIC STRESS UNDER UNFACTORED LOADS FOR BEAMS

STORY	BEAM	MAXIMUM ELASTIC STRESS
1	1	36,000
2	1	36,000
3	1	36,000
1	2	36,000
2	2	36,000
3	2	36,000
1	3	36,000
2	3	36,000
3	3	36,000

MAXIMUM PERMISSIBLE ELASTIC STRESS UNDER UNFACTORED LOADS FOR COLUMNS

STORY	COLUMN	MAXIMUM ELASTIC STRESS
1	1	36,000
2	1	36,000
3	1	36,000
1	2	36,000
2	2	36,000
3	2	36,000
1	3	36,000
2	3	36,000
3	3	36,000
1	4	36,000
2	4	36,000
3	4	36,000

MODES OF PANEL RESISTANCE FOR PLASTIC DESIGN

STORY	PANEL	MODE OF RESISTANCE
1	1	MOMENT
1	2	MOMENT
1	3	BOTH MOMENT AND TRUSS
2	1	MOMENT

2	2	MOMENT
2	3	BOTH MOMENT AND TRUSS
3	1	MOMENT
3	2	MOMENT
3	3	BOTH MOMENT AND TRUSS

N O T E ** WEAK BEAM - STRONG COLUMN CONSTRAINT NOT ACTIVE

N O T E ** COLUMN EFFECTIVE LENGTH COMPUTATION FOR PLASTIC DESIGN ACTIVE

N O T E ** COLUMN ELONGATION AND SHORTENING INCLUDED IN P-DELTA EFFECT IN PLASTIC DESIGN

CONVERGENCE TOLERANCE FOR P-DELTA DESIGN IN PLASTIC DESIGN = .075

BEAM SECTION PROPERTY TABLE

SECTION	LB/FT	A	DEPTH	IZ	IY	SZ	ZZ	RZ	RY
6JR44	4.4	1.30	6.00	7.3	.2	2.4	2.8	2.57	.36
8JR65	6.5	1.92	8.00	18.7	.3	4.7	5.4	3.12	.42
10JR9	9.0	2.64	10.00	39.0	.6	7.8	9.2	3.85	.48
12JR118	11.8	3.45	12.00	72.2	1.0	12.0	14.3	4.57	.53
10B15	15.0	4.40	10.00	68.8	2.8	13.8	16.0	3.95	.80
12B165	16.5	4.86	12.00	105.3	2.8	17.5	20.6	4.65	.76
14B172	17.2	5.05	14.00	147.3	2.7	21.0	24.7	5.40	.72
14B22	22.0	6.47	13.72	197.4	6.4	28.8	33.0	5.52	.99
16B26	26.0	7.65	15.65	298.1	8.7	38.1	43.9	6.24	1.07
14WF30	30.0	8.81	13.86	289.6	17.5	41.8	47.1	5.73	1.41
16B31	31.0	9.12	15.84	372.5	11.6	47.0	53.8	6.39	1.13
14WF34	34.0	10.00	14.00	339.2	21.3	48.5	54.5	5.83	1.46
16WF36	36.0	10.59	15.85	446.3	22.1	56.3	63.9	6.49	1.45
16WF40	40.0	11.77	16.00	515.5	26.5	64.4	72.7	6.62	1.50
18WF45	45.0	13.24	17.86	700.5	31.9	78.9	89.6	7.30	1.55
18WF50	50.0	14.71	18.00	800.6	37.2	89.0	100.8	7.38	1.59
21WF55	55.0	16.18	20.80	1140.7	44.0	109.7	125.4	8.40	1.65
21WF62	62.0	18.23	20.99	1326.8	53.1	126.4	144.1	8.53	1.71
24WF68	68.0	20.00	23.71	1814.5	63.8	153.1	175.5	9.53	1.79
24WF76	76.0	22.37	23.91	2096.4	76.5	175.4	200.1	9.68	1.85
27WF84	84.0	24.71	26.69	2824.8	95.7	211.7	243.2	10.69	1.97
27WF94	94.0	27.65	26.91	3265.7	115.1	242.8	277.7	10.87	2.04
30WF99	99.0	29.11	29.64	3988.6	116.9	269.1	312.0	11.70	2.00
30WF108	108.0	31.77	29.82	4461.0	135.1	299.2	345.5	11.85	2.06
30WF116	116.0	34.13	30.00	4919.1	153.2	327.9	377.6	12.00	2.12
33WF118	118.0	34.71	32.86	5886.9	170.3	358.3	414.3	13.02	2.22
33WF130	130.0	38.26	33.10	6699.0	201.4	404.8	466.0	13.23	2.29
33WF135	135.0	39.70	33.59	7796.1	207.1	438.6	509.1	14.01	2.28
36WF150	150.0	44.16	35.84	9012.1	250.4	502.9	579.0	14.29	2.38
36WF160	160.0	47.09	36.00	9738.8	275.4	541.0	623.5	14.38	2.42
36WF170	170.0	49.98	36.16	10470.0	300.6	579.1	666.7	14.47	2.45
36WF182	182.0	53.54	36.32	11281.5	327.7	621.2	716.9	14.52	2.47
36WF194	194.0	57.11	36.48	12103.4	355.4	663.6	767.2	14.56	2.49
36WF230	230.0	67.73	35.88	14988.4	870.9	835.5	942.7	14.88	3.59
36WF245	245.0	72.03	36.06	16092.2	944.7	892.5	1008.0	14.95	3.62
36WF260	260.0	76.56	36.24	17233.8	1020.6	951.1	1076.0	15.00	3.65
36WF280	280.0	82.32	36.50	18819.3	1127.5	1031.2	1167.0	15.12	3.70
36WF300	300.0	88.17	36.72	20290.2	1225.2	1105.1	1255.0	15.17	3.73
12WF45	45.0	13.24	12.06	350.8	50.0	58.2	64.9	5.15	1.94
10WF54	54.0	15.88	10.12	305.7	103.9	60.4	67.0	4.39	2.56
12WF50	50.0	14.71	12.19	394.5	56.4	64.7	72.6	5.18	1.96
10WF72	72.0	21.18	10.50	420.7	141.8	80.1	90.7	4.46	2.59
10WF89	89.0	26.19	10.88	542.4	180.6	97.7	114.4	4.55	2.63
12WF79	79.0	23.22	12.38	663.0	216.4	107.1	119.3	5.34	3.05
18WF60	60.0	17.64	18.25	984.0	47.1	107.8	122.6	7.47	1.63
14WF74	74.0	21.76	14.19	796.8	133.5	112.3	125.6	6.05	2.48
10WF100	100.0	29.43	11.12	625.0	206.6	112.4	130.1	4.61	2.65
18WF64	64.0	18.80	17.87	1045.8	70.3	117.0	131.6	7.46	1.93
14WF78	78.0	22.94	14.06	851.2	206.9	121.1	134.0	6.09	3.00
12WF92	92.0	27.06	12.62	788.9	256.4	125.0	140.2	5.40	3.08

18WF70	70.0	20.56	18.00	1153.9	78.5	128.2	144.7	7.49	1.95
16WF78	78.0	22.92	16.32	1042.6	87.5	127.8	145.5	6.74	1.95
10WF112	112.0	32.92	11.38	710.7	235.4	126.3	147.5	4.67	2.67
12WF99	99.0	29.09	12.75	858.5	278.2	134.7	151.8	5.43	3.09
18WF77	77.0	22.63	18.16	1286.8	88.6	141.7	160.5	7.54	1.98
12WF106	106.0	31.19	12.88	930.7	300.9	144.5	163.4	5.46	3.11
16WF88	88.0	25.87	16.16	1222.6	185.2	151.3	169.0	6.87	2.67
18WF85	85.0	24.97	18.32	1429.9	99.4	156.1	177.6	7.57	2.00
12WF120	120.0	35.31	13.12	1071.7	345.1	163.4	186.4	5.51	3.13
21WF82	82.0	24.10	20.86	1752.4	89.6	168.0	191.6	8.53	1.93
18WF96	96.0	28.22	18.16	1674.7	206.8	184.4	206.0	7.70	2.71
18WF105	105.0	30.86	18.32	1852.5	231.0	202.2	226.5	7.75	2.73
18WF114	114.0	33.51	18.48	2033.8	255.6	220.1	247.9	7.79	2.76
21WF112	112.0	32.93	21.00	2620.6	289.7	249.6	278.0	8.92	2.96
14WF158	158.0	46.47	15.00	1900.6	745.0	253.4	286.3	6.40	4.00
14WF167	167.0	49.09	15.12	2020.8	790.2	267.3	302.9	6.42	4.01
24WF110	110.0	32.36	24.16	3315.0	229.1	274.4	307.7	10.12	2.66
12WF190	190.0	55.86	14.38	1892.5	589.7	263.2	311.5	5.82	3.25
21WF127	127.0	37.34	21.24	3017.2	338.6	286.1	317.8	8.99	3.01
24WF120	120.0	35.29	24.31	3635.3	254.0	299.1	336.6	10.15	2.68
21WF142	142.0	41.76	21.46	3403.1	385.9	317.2	357.0	9.03	3.04
14WF202	202.0	59.39	15.63	2538.8	979.7	324.9	373.6	6.54	4.06
24WF145	145.0	42.62	24.49	4561.0	434.3	372.5	416.0	10.34	3.19
24WF160	160.0	47.04	24.72	5110.3	492.6	413.5	463.7	10.45	3.23
14WF264	264.0	77.63	16.50	3526.0	1331.2	427.4	502.4	6.74	4.14
27WF160	160.0	47.04	27.08	6018.6	458.0	444.5	504.3	11.31	3.12
14WF287	287.0	84.37	16.81	3912.1	1466.5	465.5	551.6	6.81	4.17
27WF177	177.0	52.10	27.31	6728.6	518.9	492.8	556.9	11.36	3.16
33WF152	152.0	44.71	33.50	8147.6	256.1	486.4	558.3	13.50	2.39
30WF172	172.0	50.65	29.88	7891.5	550.1	528.2	593.0	12.48	3.30
30WF190	190.0	55.90	30.12	8825.9	624.6	586.1	659.6	12.57	3.34
30WF210	210.0	61.78	30.38	9872.4	707.9	649.9	733.9	12.64	3.38
14WF398	398.0	116.98	18.31	6013.7	2169.7	656.9	803.0	7.17	4.31
33WF240	240.0	70.52	33.50	13585.1	874.3	811.1	918.2	13.88	3.52
36WF230	230.0	67.73	35.88	14988.4	870.9	835.5	942.7	14.88	3.59
36WF280	280.0	82.32	36.50	18819.3	1127.5	1031.2	1167.0	15.12	3.70
36WF300	300.0	88.17	36.72	20290.2	1225.2	1105.1	1255.0	15.17	3.73

COLUMN SECTION PROPERTY TABLE

SECTION	LB/FT	A	DEPTH	IZ	IY	SZ	ZZ	RZ	RY
6WF20	20.0	5.90	6.20	41.7	13.3	13.4	15.0	2.66	1.50
8WF24	24.0	7.06	7.93	82.5	18.2	20.8	23.1	3.42	1.61
8WF28	28.0	8.23	8.06	97.8	21.6	24.3	27.1	3.45	1.62
8WF31	31.0	9.12	8.00	109.7	37.0	27.4	30.9	3.47	2.01
8WF35	35.0	10.30	8.12	126.5	42.5	31.1	34.7	3.50	2.03
10WF39	39.0	11.48	9.94	209.7	44.9	42.2	47.0	4.27	1.98
12WF40	40.0	11.77	11.94	310.1	44.1	51.9	57.6	5.13	1.94
14WF43	43.0	12.65	13.68	429.0	45.1	62.7	69.7	5.82	1.89
14WF48	48.0	14.11	13.81	484.9	51.3	70.2	78.5	5.86	1.91
14WF53	53.0	15.59	13.94	542.1	57.3	77.8	87.1	5.90	1.92
12WF58	58.0	17.06	12.19	476.1	107.4	78.1	86.5	5.28	2.51
14WF61	61.0	17.94	13.91	641.5	107.3	92.2	102.4	5.98	2.45
14WF74	74.0	21.76	14.19	796.8	133.5	112.3	125.6	6.05	2.48
14WF78	78.0	22.94	14.06	851.2	206.9	121.1	134.0	6.09	3.00

12WF79	79.0	23.22	12.38	663.0	216.4	107.1	119.3	5.34	3.05
14WF84	84.0	24.71	14.18	928.4	225.5	130.9	145.4	6.13	3.02
12WF99	99.0	29.09	12.75	858.5	278.2	134.7	151.8	5.43	3.09
14WF111	111.0	32.65	14.37	1266.5	454.9	176.3	196.0	6.23	3.73
14WF119	119.0	34.99	14.50	1373.1	491.8	189.4	210.9	6.26	3.75
14WF127	127.0	37.33	14.62	1476.7	527.6	202.0	225.9	6.29	3.76
14WF136	136.0	39.98	14.75	1593.0	567.7	216.0	242.7	6.31	3.77
14WF142	142.0	41.85	14.75	1672.2	660.1	226.7	254.8	6.32	3.97
14WF150	150.0	44.08	14.88	1786.9	702.5	240.2	270.2	6.37	3.99
14WF158	158.0	46.47	15.00	1900.6	745.0	253.4	286.3	6.40	4.00
14WF167	167.0	49.09	15.12	2020.8	790.2	267.3	302.9	6.42	4.01
14WF176	176.0	51.73	15.25	2149.6	837.9	281.9	321.3	6.45	4.02
14WF184	184.0	54.07	15.38	2274.8	882.7	295.0	337.5	6.49	4.04
14WF193	193.0	56.73	15.50	2402.4	930.1	310.0	355.1	6.51	4.05
14WF202	202.0	59.39	15.63	2538.8	979.7	324.9	373.6	6.54	4.06
14WF211	211.0	62.07	15.75	2671.4	1028.6	339.2	391.7	6.56	4.07
14WF219	219.0	64.36	15.87	2798.2	1073.2	352.6	408.0	6.59	4.08
14WF228	228.0	67.06	16.00	2942.4	1124.8	367.8	427.2	6.62	4.10
14WF237	237.0	69.69	16.12	3080.9	1174.8	382.2	445.4	6.65	4.11
14WF246	246.0	72.33	16.25	3228.9	1226.6	397.4	464.5	6.68	4.12
14WF264	264.0	77.63	16.50	3526.0	1331.2	427.4	502.4	6.74	4.14
14WF287	287.0	84.37	16.81	3912.1	1466.5	465.5	551.6	6.81	4.17
14WF314	314.0	92.30	17.19	4399.4	1631.4	511.9	611.5	6.90	4.20
14WF320	320.0	94.12	16.81	4141.7	1635.1	492.8	592.2	6.63	4.17
14WF342	342.0	100.59	17.56	4911.5	1806.9	559.4	673.0	6.99	4.24
14WF370	370.0	108.78	17.94	5454.2	1986.0	608.1	737.3	7.08	4.27
14WF398	398.0	116.98	18.31	6013.7	2169.7	656.9	803.0	7.17	4.31
14WF426	426.0	125.25	18.69	6610.3	2359.5	707.4	869.3	7.26	4.34
14WF455	455.0	133.73	19.05	7214.9	2561.2	757.5	986.0	7.35	4.38
14WF500	500.0	146.95	19.63	8234.1	2882.7	839.1	1099.0	7.48	4.43
14WF550	550.0	161.75	20.26	9443.1	3256.7	932.2	1241.0	7.64	4.49
14WF605	605.0	177.85	20.94	10842.3	3600.9	1035.7	1403.0	7.81	4.55
14WF665	665.0	195.51	21.67	12477.7	4166.2	1151.7	1567.0	7.99	4.62
14WF730	730.0	214.65	22.44	14371.4	4716.8	1280.6	1770.0	8.18	4.69

BRACING SECTION PROPERTY TABLE

SECTION	LB/FT	A	DEPTH	IZ	IY	SZ	ZZ	RZ	RY
1EAN1.6	1.6	.47							
1EAN2.02	2.0	.59							
1EAN2.44	2.5	.72							
1EAN2.88	2.9	.84							
2EAN3.3	3.3	.96							
2EAN4.88	4.9	1.45							
3UAN6.1	6.1	1.80							
3UAN9.0	9.0	2.62							
4UAN11.6	11.6	3.38							
5UAN13.2	13.2	3.84							
4UAN14.4	14.4	4.18							
4UAN15.4	15.4	4.50							
4UAN17.0	17.0	4.96							
4UAN18.2	18.2	5.34							
4UAN19.6	19.6	5.74							
4UAN21.2	21.2	6.18							
4UAN22.2	22.2	6.50							

6UAN23.4	23.4	6.88
6UAN24.6	24.6	7.22
5UAN25.6	25.6	7.50
5UAN27.2	27.2	8.00
6UAN28.6	28.6	8.36
7UAN31.6	31.6	9.24
8UAN34.4	34.4	10.12
8UAN39.2	39.2	11.50
8UAN57.4	57.4	16.88

OUTPUT FINAL DESIGN AND ANALYSIS DATA

DESIGN PLASTIC TO CONVERGENCE

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* S T A R T   P L A S T I C   D E S I G N *
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DIAGNOSTIC MESSAGES -- PLASTIC DESIGN
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***** N O T E  -- ASSUMED INITIAL RELATIVE STORY DEFLECTION HAS BEEN INPUT LESS THAN OR EQUAL TO .01 FOR STORY NO.  1
A VALUE OF .0005*(STORY HIEGHT) =    .072 WILL BE ASSUMED. *****

***** N O T E  -- ASSUMED INITIAL RELATIVE STORY DEFLECTION HAS BEEN INPUT LESS THAN OR EQUAL TO .01 FOR STORY NO.  2
A VALUE OF .0005*(STORY HIEGHT) =    .072 WILL BE ASSUMED. *****

***** N O T E  -- ASSUMED INITIAL RELATIVE STORY DEFLECTION HAS BEEN INPUT LESS THAN OR EQUAL TO .01 FOR STORY NO.  3
A VALUE OF .0005*(STORY HIEGHT) =    .072 WILL BE ASSUMED. *****

***** N O T E -- YOU HAVE NOT SPECIFIED A MAXIMUM LATERALLY UNSUPPORTED BEAM LENGTH FOR ALL BEAMS.
THE UNSUPPORTED LENGTH OF 48.0 INCHES WILL BE ASSUMED FOR BEAMS WHOSE LATERALLY UNSUPPORTED LENGTH IS NOT SPECIFIED. *****

***** N O T E -- YOU HAVE NOT SPECIFIED A MAXIMUM LATERALLY UNSUPPORTED COLUMN LENGTH FOR ALL COLUMNS.
THE APPROPRIATE STORY HIEGHT WILL BE ASSUMED FOR COLUMNS WHOSE LATERALLY UNSUPPORTED LENGTH IS NOT SPECIFIED. *****

***** N O T E -- YOU HAVE NOT SPECIFIED A MAXIMUM PERMISSIBLE BEAM DEPTH FOR ALL BEAMS.
A MAXIMUM DEPTH OF 10000.0 INCHES WILL BE ASSUMED FOR BEAMS WHOSE MAXIMUM DEPTH IS NOT SPECIFIED. *****

***** N O T E -- YOU HAVE NOT SPECIFIED A MAXIMUM PERMISSIBLE COLUMN DEPTH FOR ALL COLUMNS.
A MAXIMUM DEPTH OF 10000.0 INCHES WILL BE ASSUMED FOR COLUMNS WHOSE MAXIMUM IS NOT SPECIFIED. *****

SYSTEM WARNING 4.20 - AN ER MCORES FOR   4608 WORDS HAS BEEN ISSUED

SYSTEM WARNING 4.20 - AN ER MCORES FOR    512 WORDS HAS BEEN ISSUED

SYSTEM WARNING 4.20 - AN ER MCORES FOR   1024 WORDS HAS BEEN ISSUED
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SYSTEM WARNING 4,20 - AN ER MCORES FOR 512 WORDS HAS BEEN ISSUED

***** N O T E ** PLASTIC DESIGN HAS CONVERGED AFTER 2 DESIGN CYCLES *****

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OUTPUT OF FINAL PLASTIC DESIGN RESULTS

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STORY	BAY	SECT. NO.(D.L.)	SECT. NO.(D.L.+W.L.)	GRAVITY	GRAVITY + WIND	
BEAMS						
1	1	9	9	16B26	16B26	
1	2	4	4	12JR11P8	12JR11P8	
1	3	15	15	18WF45	18WF45	
COLUMNS						
1	1	6	8	10WF39	14WF43	
1	2	5	6	8WF35	10WF39	
1	3	9	9	14WF48	14WF48	
1	4	10	11	14WF53	12WF58	
BRACES						
BEAMS						
2	1	13	13	16WF36	16WF36	
2	2	7	7	14B17P2	14B17P2	
2	3	17	17	21WF55	21WF55	
COLUMNS						
2	1	7	8	12WF40	14WF43	
2	2	6	6	10WF39	10WF39	
2	3	9	9	14WF48	14WF48	
2	4	10	11	14WF53	12WF58	
BRACES						
2	3		1		1EAN1,6	...BRACE TYPE 1 (TENSION FOR WIND FROM RIGHT).
2	3		1		1EAN1,6	...BRACE TYPE 2 (TENSION FOR WIND FROM LEFT).
BEAMS						
3	1	13	13	16WF36	16WF36	
3	2	7	7	14B17P2	14B17P2	
3	3	17	17	21WF55	21WF55	
COLUMNS						
3	1	9	10	14WF48	14WF53	
3	2	9	9	14WF48	14WF48	

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 3      3      12              12                      14WF61         14WF61
 3      4      13              13                      14WF74         14WF74
BRACES
 3      3                       1                                     1EAN1,6  ...BRACE TYPE 1 (TENSION FOR
                                                                                   WIND FROM RIGHT),
 3      3                       1                                     1EAN1,6  ...BRACE TYPE 2 (TENSION FOR
                                                                                   WIND FROM LEFT),
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* STORY PANEL SHEAR DISTRIBUTION.

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STORY 1,   REQUIRED STORY SHEAR CAPACITY=    8,332,
WIND FROM LEFT, DISTRIBUTION BY PANEL...    6,665    1,666     ,000
WIND FROM RIGHT,DISTRIBUTION BY PANEL...    1,666    1,666    4,999
STORY 2,   REQUIRED STORY SHEAR CAPACITY=   18,181,
WIND FROM LEFT, DISTRIBUTION BY PANEL...    2,616    3,636   11,929
WIND FROM RIGHT,DISTRIBUTION BY PANEL...    3,636    2,616   11,929
STORY 3,   REQUIRED STORY SHEAR CAPACITY=   27,744,
WIND FROM LEFT, DISTRIBUTION BY PANEL...    5,549    5,549   16,647
WIND FROM RIGHT,DISTRIBUTION BY PANEL...    5,549    5,549   16,647
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TOTAL MATERIAL COST AND WEIGHT AFTER PLASTIC DESIGN PART.

MEMBER	WEIGHT (TONS)	COST (DOLLARS)
BEAMS	3,26	1304,52
COLUMNS	3,67	1468,80
BRACES	,10	38,99
TOTAL	7,03	2812,31

WEIGHT AND COST BY GRADE OF STEEL,

BEAMS, 36,0 KSI.,   3,241 TONS,   1304,92 DOLLARS,
COLUMNS, 36,0 KSI.,   3,672 TONS,   1468,85 DOLLARS,
BRACES, 36,0 KSI.,   ,097 TONS,   38,99 DOLLARS,

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OUTPUT OF FINAL PLASTIC ANALYSIS RESULTS
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NOTE -- OUTPUT OF RIGHT AND LEFT BEAM MOMENTS AND TOP AND BOTTOM
COLUMN MOMENTS DUE TO THE FACTORED GRAVITY AND THE FACTORED GRAVITY
PLUS WIND LOADING CONDITIONS IS AT THE JOINT CENTERS,
WHILE OUTPUT OF REQUIRED REDUCED PLASTIC MOMENT CAPACITIES FOR BEAMS AND COLUMNS
IS AT THE BEAM AND COLUMN FACES RESPECTIVELY.

OUTPUT OF REQUIRED DESIGN MOMENT AND AXIAL FORCE DIAGRAMS, FACTORED GRAVITY LOAD CONDITION (F1 = 1,70)

AXIAL FORCE AND MOMENT DIAGRAM FOR BEAMS

STORY	BEAM	AXIAL FORCE (KIPS)	MOMENT LEFT (KIP-IN.)	MOMENT CENTER (KIP-IN.)	MOMENT RIGHT (KIP-IN.)
1	1	,00	-1605,29	1054,71	1605,29
1	2	,00	-596,47	505,13	595,47
1	3	,00	-3123,08	2874,52	3123,08
2	1	,00	-2333,02	2114,18	2333,02
2	2	,00	-940,44	796,42	940,44
2	3	,00	-4226,56	3890,18	4226,56
3	1	,00	-2352,15	2095,05	2352,15
3	2	,00	-952,01	784,04	952,01
3	3	,00	-4228,07	3888,67	4220,07

AXIAL FORCE AND MOMENT DIAGRAM FOR COLUMNS (INCLUDES LIVE LOAD REDUCTION FOR AXIAL FORCE)

STORY   COLUMN   AXIAL FORCE (KIPS)   MOMENT TOP (KIP-IN.)   MOMENT BOTTOM (KIP-IN.)

1	1	77,69	1605,29	1166,51
1	2	94,35	-1008,02	-696,29
1	3	114,75	2526,61	1643,06
1	4	98,09	-3123,00	-2113,28
2	1	199,44	1166,51	1176,07
2	2	217,62	-696,29	-700,07
2	3	259,74	1643,06	1638,03
2	4	241,56	-2113,28	-2114,04
3	1	315,41	1176,07	1176,07
3	2	319,76	-700,07	-700,07
3	3	382,20	1638,03	1638,03
3	4	378,58	-2114,04	-2114,04

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OUTPUT OF REQUIRED DESIGN MOMENT AND AXIAL FORCE DIAGRAMS, FACTORED GRAVITY + FACTORED LATERAL LOAD CONDITION (F2 = 1,30)

OUTPUT FOR WIND FROM THE LEFT ...

AXIAL FORCE AND MOMENT DIAGRAM FOR BEAMS

STORY	BEAM	AXIAL FORCE (KIPS)	MOMENT LEFT (KIP-IN,)	MOMENT CENTER (KIP-IN,)	MOMENT RIGHT (KIP-IN,)
1	1	2,16	-817,51	1244,56	1373,38
1	2	-.16	-358,27	417,04	492,45
1	3	-,05	-2388,24	2198,16	2388,24
2	1	11,00	-1347,72	1757,32	1939,23
2	2	11,10	-452,26	692,94	818,24
2	3	6,03	-2844,07	3100,30	3360,16
3	1	5,93	-1365,33	1741,15	1952,96
3	2	4,30	-245,99	750,03	968,02
3	3	10.57	-2550,42	3194,89	3473,64

AXIAL FORCE AND MOMENT DIAGRAM FOR COLUMNS (INCLUDES LIVE LOAD REDUCTION FOR AXIAL FORCE)

STORY	COLUMN	AXIAL FORCE (KIPS)	MOMENT TOP (KIP-IN,)	MOMENT BOTTOM (KIP-IN,)
1	1	57,09	817,51	594,06
1	2	73,53	-1015,11	-715,55
1	3	88,60	1895,79	1227,02
1	4	75,01	-2388,24	-1616.04
2	1	147,73	753,66	759,84
2	2	167,72	-771,42	-777,04
2	3	200,54	798,91	793,95
2	4	180,28	-1752,34	-1752,97
3	1	233,96	605,49	605,49

3	2	283.68	-931.03	-931,03
3	3	294,05	847,65	847.65
3	4	300.56	-1720,67	-1720,67

AXIAL FORCE DIAGRAM FOR BRACING

STORY	BAY	BRACE 1 AXIAL FORCE (KIPS) (TENSION FOR WIND FROM RIGHT)	BRACE 2 AXIAL FORCE (KIPS) (TENSION FOR WIND FROM LEFT)
1	1	,00	,00
1	2	,00	,00
1	3	,00	,00
2	1	,00	,00
2	2	,00	,00
2	3	,00	-5,07
3	1	,00	,00
3	2	,00	,00
3	3	,00	-12,07

OUTPUT OF REQUIRED DESIGN MOMENT AND AXIAL FORCE DIAGRAMS, FACTORED GRAVITY + FACTORED LATERAL LOAD CONDITION (F2 = 1,30)

OUTPUT FOR WIND FROM THE RIGHT ...

AXIAL FORCE AND MOMENT DIAGRAM FOR BEAMS

STORY	BEAM	AXIAL FORCE (KIPS)	MOMENT LEFT (KIP-IN.)	MOMENT CENTER (KIP-IN.)	MOMENT RIGHT (KIP-IN.)
1	1	,30	-1269,03	1185,46	1123,06
1	2	1,39	-892,45	417,04	330,27
1	3	3,20	-2500,02	2301,05	2070,68
2	1	,34	-1878,95	1702,70	1517,23
2	2	1,19	-798,47	676,20	505,30
2	3	6,43	-3444,02	3169,92	2625,99
3	1	,27	-1973,31	1758,68	1310,92
3	2	1,46	-800,81	733,89	299,79
3	3	14,18	-3473,64	3194,89	2550,42

AXIAL FORCE AND MOMENT DIAGRAM FOR COLUMNS (INCLUDES LIVE LOAD REDUCTION FOR AXIAL FORCE)

STORY	COLUMN	AXIAL FORCE (KIPS)	MOMENT TOP (KIP-IN.)	MOMENT BOTTOM (KIP-IN.)
1	1	59,99	1264,03	918,52
1	2	72,50	-632,61	-429,33
1	3	88,10	2141,75	1409,24
1	4	73,73	-2070,68	-1401,16
2	1	154,60	960,43	968,30
2	2	167,39	-289,44	-290,12
2	3	201,36	1529,28	1527,16
2	4	181,02	-1228,83	-1229,27

3	1	246,04	1005,01	1005,01
3	2	246,73	-131,99	-131,99
3	3	295,41	1696,69	1696,69
3	4	281,06	-1321,15	-1321,15

AXIAL FORCE DIAGRAM FOR BRACING

STORY	BAY	BRACE 1 AXIAL FORCE (KIPS) (TENSION FOR WIND FROM RIGHT)	BRACE 2 AXIAL FORCE (KIPS) (TENSION FOR WIND FROM LEFT)
1	1	,00	,00
1	2	,00	,00
1	3	,00	,00
2	1	,00	,00
2	2	,00	,00
2	3	-5,07	,00
3	1	,00	,00
3	2	,00	,00
3	3	-12,07	,00

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OUTPUT OF REQUIRED REDUCED PLASTIC MOMENT CAPACITIES IN THE PRESENCE OF AXIAL FORCE FOR BEAMS AND COLUMNS
(THE REDUCED PLASTIC MOMENT CAPACITY IS THE MAXIMUM MOMENT A MEMBER CAN EXPERIENCE IN THE PRESENCE OF AXIAL FORCE)

NOTE -- THIS IS THE MAXIMUM REQUIRED REDUCED PLASTIC MOMENT AT THE END OF A COLUMN OR AT
THE END OR CENTER OF A BEAM OF THE THREE FACTORED LOADING CONDITIONS
(F1*(GRAVITY),F2*(GRAVITY+WIND LEFT),F2*(GRAVITY+WIND RIGHT)) FOR A MEMBER.
THIS MOMENT IS USED IN THE INTERACTION EQUATIONS
FOR THE APPLIED MOMENT VALUE M. HOWEVER, THE ACTUAL AXIAL FORCE
IS USED IN THE INTERACTION EQUATIONS WHEN CHECKING GRAVITY AND
COMBINATION LOADING CONDITIONS. THIS IS CONSERVATIVE.

BEAMS

STORY	BEAM	REQUIRED REDUCED PLASTIC MOMENT CAPACITY (KIP-IN.)
1	1	1454,71
1	2	505,13
1	3	2874,52
2	1	2114,18
2	2	796,42
2	3	3690,18
3	1	2395,05
3	2	784,84
3	3	3688,67

COLUMNS

STORY	COLUMN	REQUIRED REDUCED PLASTIC MOMENT CAPACITY (KIP-IN.)
1	1	1453.71
1	2	942.99
1	3	2246.75
1	4	2771.63
2	1	1047.15
2	2	701.77
2	3	1406.10
2	4	1808.73
3	1	1046.62
3	2	340.51
3	3	1408.84
3	4	1808.68

OUTPUT OF FINAL RELATIVE STORY DEFLECTIONS AT COLLAPSE

STORY	RELATIVE STORY DEFLECTION
1	.501461
2	.498285
3	.493714

OUTPUT OF COLUMN EFFECTIVE LENGTH FACTORS FOR PLASTIC DESIGN (BEAM EFFECTIVE LENGTH FACTORS = 1.00)

STORY	COLUMN	K - WIND FROM LEFT	K - WIND FROM RIGHT
1	1	1.780000	1.780000
1	2	1.300000	1.300000
1	3	1.440000	1.440000
1	4	1.530000	1.530000
2	1	1.000000	1.000000
2	2	1.000000	1.000000
2	3	1.000000	1.000000

2	4	1.000000	1.000000
3	1	1.000000	1.000000
3	2	1.000000	1.000000
3	3	1.000000	1.000000
3	4	1.000000	1.000000

OUTPUT OF VALUES FOR AISC COLUMN INTERACTION EQUATIONS 2.42 AND 2.43 AFTER COMPLETION OF PLASTIC DESIGN

STORY	COLUMN	EQ. 2.42-WIND LEFT	EQ. 2.42-WIND RIGHT	EQ. 2.43-WIND LEFT	EQ. 2.43-WIND RIGHT
1	1	.728858	.735691	.842612	.849014
1	2	.830041	.831715	.989173	.980826
1	3	.848337	.847184	.983135	.981453
1	4	.876417	.000000	.955714	.952256
2	1	.776618	.693146	.950021	.873321
2	2	.757327	.000000	.957673	.956182
2	3	.915261	.018062	.841939	.750681
2	4	.798799	.000000	.616088	.601657
3	1	.699734	.721257	.807944	.918126
3	2	.731771	.000000	.934598	.992914
3	3	.862184	.785929	.770609	.722705
3	4	.722668	.850972	.632675	.736690

OUTPUT OF VALUES FOR AISC BEAM INTERACTION EQUATION 2.43 AFTER COMPLETION OF PLASTIC DESIGN

STORY	BEAM	EQ. 2.43-WIND LEFT	EQ. 2.43-WIND RIGHT
1	1	.804288	.795305
1	2	.927050	.901950
1	3	.757337	.766661
2	1	.816528	.782279
2	2	.876025	.814007
2	3	.745416	.745271
3	1	.793136	.774977
3	2	.821739	.894269
3	3	.754898	.762650

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*   E N D   P L A S T I C   D E S I G N          *
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DESIGN ELASTIC TO CONVERGENCE

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*  S T A R T   E L A S T I C   D E S I G N  *
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*********************************************************************************************************************
DIAGNOSTIC MESSAGES -- ELASTIC DESIGN
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     ***** N O T E -- YOU HAVE NOT SPECIFIED A MAXIMUM LATERALLY UNSUPPORTED BEAM LENGTH FOR ALL BEAMS,
     THE UNSUPPORTED LENGTH OF 48.0 INCHES WILL BE ASSUMED FOR BEAMS WHOSE LATERALLY UNSUPPORTED LENGTH IS NOT SPECIFIED, *****

     ***** N O T E -- YOU HAVE NOT SPECIFIED A MAXIMUM LATERALLY UNSUPPORTED COLUMN LENGTH FOR ALL COLUMNS,
     THE APPROPRIATE STORY HIEGHT WILL BE ASSUMED FOR COLUMNS WHOSE LATERALLY UNSUPPORTED LENGTH IS NOT SPECIFIED, *****

     ***** N O T E -- YOU HAVE NOT SPECIFIED A MAXIMUM PERMISSIBLE BEAM DEPTH FOR ALL BEAMS,
     A MAXIMUM DEPTH OF 10000.0 INCHES WILL BE ASSUMED FOR BEAMS WHOSE MAXIMUM DEPTH IS NOT SPECIFIED, *****

     ***** N O T E -- YOU HAVE NOT SPECIFIED A MAXIMUM PERMISSIBLE COLUMN DEPTH FOR ALL COLUMNS,
     A MAXIMUM DEPTH OF 10000.0 INCHES WILL BE ASSUMED FOR COLUMNSWHOSE MAXIMUM DEPTH IS NOT SPECIFIED, *****


***** N O T E -- ELASTIC DESIGN HAS CONVERGED AFTER   1 DESIGN CYCLES *****


*********************************************************************************************************************
FINAL ELASTIC ANALYSIS AND DESIGN OUTPUT
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OUTPUT OF MEMBER FORCES, LOCAL SIGN CONVENTION -- GRAVITY LOADS ONLY (KIPS, INCHES)

STORY	BEAM	MOMENT LEFT	MOMENT RIGHT	SHEAR LEFT	SHEAR RIGHT	AXIAL
1	1	-1006,360	1035,993	-29,877	30,123	12,698
1	2	-869,782	553,580	-17,418	18,582	5,407
1	3	-1996,551	1858,180	-42,812	41,508	23,366
2	1	-1570,666	1602,225	-43,868	43,731	-2,216
2	2	-732,891	805,355	-27,877	28,003	-,314
2	3	-2863,987	2790,329	-57,059	56,621	-5,199
3	1	-1547,194	1611,598	-43,332	43,868	-2,107
3	2	-725,356	832,101	-27,639	29,121	-1,737
3	3	-2834,762	2717,526	-57,189	56,491	-3,869

STORY	COLUMN	MOMENT TOP	MOMENT BOTTOM	SHEAR TOP	SHEAR BOTTOM	AXIAL
1	1	1006,360	822,178	12,698	12,698	45,577
1	2	-566,251	-483,729	-7,292	-7,292	55,041
1	3	1442,971	1143,172	17,959	17,959	68,494
1	4	-1858,180	-1506,521	-23,366	-23,366	57,288
2	1	748,488	760,985	10,482	10,482	121,845
2	2	-385,605	-390,530	-5,390	-5,390	130,189
2	3	915,451	967,296	13,075	13,075	161,936
2	4	-1283,229	-1332,277	-18,167	-18,167	145,909
3	1	786,210	419,914	8,376	8,376	196,377
3	2	-495,704	-227,221	-5,020	-5,020	213,156
3	3	1035,365	540,300	10,943	10,943	255,747
3	4	-1385,249	-673,695	-14,298	-14,298	234,400

STORY	BAY	BRACE	AXIAL

REACTION	AXIAL	SHEAR	MOMENT
1	196,377	8,376	419,914
2	213,156	-5,020	-227,221
3	255,747	10,943	540,300
4	234,400	-14,298	-673,695

END MEMBER FORCE OUTPUT

OUTPUT OF MEMBER FORCES, LOCAL SIGN CONVENTION -- GRAVITY + WIND FROM THE LEFT (KIPS, INCHES)

STORY	BEAM	MOMENT LEFT	MOMENT RIGHT	SHEAR LEFT	SHEAR RIGHT	AXIAL
1	1	-940.950	1090.572	-29.377	30.623	16.773
1	2	-447.978	577.526	-17.100	18.900	8.464
1	3	-1891.100	1968.978	-41.770	42.230	24.763
2	1	-1931.515	1716.571	-42.412	44.788	3.096
2	2	-674.074	870.260	-27.018	29.742	4.708
2	3	-2633.040	3029.617	-55.560	58.020	-.955
3	1	-1305.251	1791.980	-41.739	45.461	1.923
3	2	-635.710	921.210	-26.393	30.367	.362
3	3	-2526.970	3083.790	-55.302	58.378	.339

STORY	COLUMN	MOMENT TOP	MOMENT BOTTOM	SHEAR TOP	SHEAR BOTTOM	AXIAL
1	1	940.950	783.170	11.973	11.973	45.077
1	2	-642.594	-555.892	-8.309	-8.309	55.224
1	3	1313.618	1033.486	16.299	16.299	68.169
1	4	-1968.578	-1597.356	-24.763	-24.763	57.930
2	1	648.346	692.137	9.309	9.309	119.409
2	2	-488.605	-475.778	-6.697	-6.697	134.529
2	3	729.294	802.389	10.637	10.637	161.071
2	4	-1432.262	-1409.909	-20.016	-20.016	149.576
3	1	653.115	134.784	5.472	5.472	193.228
3	2	-680.391	-508.677	-8.257	-8.257	213.893
3	3	802.762	179.447	6.821	6.821	252.614
3	4	-1595.801	-1071.750	-18.511	-18.511	240.745

STORY	BAY	BRACE	AXIAL
2	3	2	-4.126
3	3	2	-2.006

REACTION	AXIAL	SHEAR	MOMENT
1	193.228	5.472	134.784
2	213.883	-8.257	-508.677
3	251.824	4.977	179.447
4	240.745	-18.511	-1071.750

END MEMBER FORCE OUTPUT

OUTPUT OF MEMBER FORCES, LOCAL SIGN CONVENTION -- GRAVITY + WIND FROM THE RIGHT (KIPS, INCHES)

STORY	BEAM	MOMENT LEFT	MOMENT RIGHT	SHEAR LEFT	SHEAR RIGHT	AXIAL
1	1	-1073.768	979.144	-30.394	29.606	13.380
1	2	-492.913	528.154	-17.755	18.245	7.145
1	3	-2106.106	1745.117	-43.074	40.926	26.789
2	1	-1727.784	1473.561	-44.659	42.541	-1.293
2	2	-799.435	731.494	-26.852	27.908	1.152
2	3	-3125.694	2521.947	-58.637	55.043	-.350
3	1	-1752.534	1427.683	-40.954	42.246	-1.246
3	2	-818.822	737.038	-28.948	27.312	.577
3	3	-3173.061	2352.899	-59.281	54.399	1.683

STORY	COLUMN	MOMENT TOP	MOMENT BOTTOM	SHEAR TOP	SHEAR BOTTOM	AXIAL
1	1	1073.768	853.022	13.380	13.380	46.094
1	2	-486.231	-411.676	-6.235	-6.235	54.861
1	3	1577.952	1250.782	19.644	19.644	69.819
1	4	-1745.117	-1421.382	-21.989	-21.989	56.626
2	1	874.762	865.867	12.088	12.088	122.753
2	2	-262.451	-283.345	-3.790	-3.790	133.793
2	3	1143.417	1177.173	16.115	16.115	163.733
2	4	-1100.644	-1186.002	-15.879	-15.879	143.669
3	1	886.667	674.585	10.842	10.842	199.707
3	2	-325.516	42.113	-1.968	-1.968	212.448
3	3	1250.850	901.985	15.006	15.006	259.276
3	4	-1166.897	-240.874	-9.776	-9.776	229.199

STORY	BAY	BRACE	AXIAL
2	3	1	-2.205
3	5	1	-2.411

REACTION	AXIAL	SHEAR	MOMENT
1	199.707	10.842	674.585
2	212.448	-1.968	42.113
3	259.276	15.006	901.985
4	228.249	-7.560	-240.874

END MEMBER FORCE OUTPUT

JOINT DISPLACEMENTS -- GRAVITY LOADS ONLY, UNBRACED FRAME (INCHES, RADIANS)

STORY	JOINT	X DISPLACEMENT	Y DISPLACEMENT	ROTATION
1	1	.061600	-.127947	-.002640128
1	2	.047829	-.156421	.002255093
1	3	.042078	-.152364	-.003098138
1	4	.021718	-.112515	.003793190
2	1	.011999	-.110060	-.001505008
2	2	.013746	-.132702	.001307365
2	3	.014078	-.128155	-.001625674
2	4	.017767	-.095066	.001975803
3	1	-.012387	-.062545	-.001660302
3	2	-.010729	-.074625	.001361306
3	3	-.009379	-.070996	-.001870702
3	4	-.006599	-.053439	.002220224

JOINT DISPLACEMENTS -- GRAVITY LOADS ONLY, BRACED FRAME FOR WIND FROM THE LEFT (INCHES,RADIANS)

STORY	JOINT	X DISPLACEMENT	Y DISPLACEMENT	ROTATION
1	1	.061566	-.127962	-.002636910
1	2	.047797	-.156419	.002257507
1	3	.042039	-.152321	-.003095582
1	4	.021667	-.112515	.003793216
2	1	.013026	-.110074	-.001572940
2	2	.014710	-.132700	.001313203
2	3	.014939	-.128112	-.001616913
2	4	.018443	-.095866	.001980984
3	1	-.009422	-.062548	-.001675964
3	2	-.007563	-.074824	.001352563
3	3	-.005700	-.070909	-.001879598
3	4	-.002855	-.053398	.002210100

JOINT DISPLACEMENTS -- GRAVITY LOADS ONLY, BRACED FRAME FOR WIND FROM THE RIGHT (INCHES, RADIANS)

STORY	JOINT	X DISPLACEMENT	Y DISPLACEMENT	ROTATION
1	1	.040672	-.128068	-.002631604
1	2	.026925	-.156010	.002263576
1	3	.021172	-.152021	-.003091970
1	4	.000802	-.112516	.003799543
2	1	-.005385	-.110175	-.001538182
2	2	-.003833	-.132692	.001331135
2	3	-.003831	-.127810	-.001392140
2	4	.000138	-.095871	.002017640
3	1	-.017751	-.062618	-.001612208
3	2	-.015979	-.074822	.001395633
3	3	-.014284	-.070817	-.001832955
3	4	-.011024	-.053488	.002266503

JOINT DISPLACEMENTS -- WIND FROM THE LEFT ONLY, BRACED FRAME (INCHES, RADIANS)

STORY	JOINT	X DISPLACEMENT	Y DISPLACEMENT	ROTATION
1	1	.279459	.001749	-.000357222
1	2	.275014	-.000028	-.000190190
1	3	.271906	.000862	-.000271699
1	4	.270735	-.002629	-.000321237
2	1	.202676	.001561	-.000517307
2	2	.198509	-.000001	-.000264552
2	3	.190850	.000791	-.000379550
2	4	.192053	-.002448	-.000436769
3	1	.091929	.000966	-.000681512
3	2	.088589	.000904	-.000450730
3	3	.086847	.000609	-.000469593
3	4	.083415	-.001451	-.000577181

JOINT DISPLACEMENTS -- WIND FROM THE RIGHT ONLY, BRACED FRAME (INCHES, RADIANS)

STORY	JOINT	X DISPLACEMENT	Y DISPLACEMENT	ROTATION
1	1	-.270494	-.001730	.000354182
1	2	-.271224	-.000021	.000190873
1	3	-.273016	-.001648	.000275194
1	4	-.275051	.001965	.000315371
2	1	-.193602	-.001543	.000523500
2	2	-.194308	-.000021	.000264309
2	3	-.195090	-.001582	.000365659
2	4	-.198648	.001785	.000423599
3	1	-.083447	-.000745	.000641047
3	2	-.084252	-.000032	.000436309
3	3	-.086216	-.000931	.000464763
3	4	-.090876	.001202	.000612995

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ELASTIC STRESSES AFTER COMPLETE ELASTIC STRESS AND STIFFNESS DESIGN

GRAVITY LOADS ONLY

STORY	BEAM	KSI	COLUMN	KSI
1	1	28,85	1	19,65
1	2	32,75	2	18,21
1	3	27,07	3	25,41

1			4	27.15
2	1	20.67	1	21.71
2	2	26.01	2	20.94
2	3	26.03	3	25.26
2			4	25.61
3	1	28.02	1	22.70
3	2	29.16	2	22.17
3	3	26.08	3	25.49
3			4	23.11

GRAVITY + WIND FROM THE LEFT

STORY	BEAM	KSI	COLUMN	KSI
1	1	30.82	1	18.57
1	2	30.78	2	20.04
1	3	26.82	3	23.54
1			4	26.60
2	1	30.78	1	20.48
2	2	30.94	2	23.30
2	3	27.60	3	22.05
2			4	27.33
3	1	32.01	1	20.79
3	2	32.06	2	24.85
3	3	27.77	3	22.79
3			4	25.26

STORY	BAY	BRACE	KSI
2	3	2	8.80
3	3	2	4.28

GRAVITY + WIND FROM THE RIGHT

STORY	BEAM	KSI	COLUMN	KSI
1	1	29.93	1	20.77
1	2	31.65	2	16.30
1	3	26.72	3	27.36
1			4	25.66
2	1	30.81	1	23.66
2	2	27.94	2	18.37
2	3	28.51	3	28.37
2			4	23.61
3	1	31.25	1	24.21
3	2	28.52	2	19.69
3	3	29.03	3	26.11
3			4	20.92

STORY	BAY	BRACE	KSI
2	3	1	4.70
3	3	1	5.14

****

OUTPUT OF MEMBER PROPERTY CONFIGURATION -- ELASTIC STRESS AND STIFFNESS DESIGN

STORY	BAY	BRACE TYPE	SECT. NO.	SECTION NAME
BEAMS				
1	1		9	16B26
1	2		6	12B16P5
1	3		15	18WF45
COLUMNS				
1	1		8	14WF43
1	2		6	10WF39
1	3		9	14WF48
1	4		11	12WF50
BRACES				
BEAMS				
2	1		13	16WF36
2	2		8	14B22
2	3		17	21WF55
COLUMNS				
2	1		8	14WF43
2	2		6	10WF39
2	3		9	14WF48
2	4		11	12WF58
BRACES				
2	3	1	1	1EAN1.6
2	3	2	1	1EAN1.6
BEAMS				
3	1		13	16WF36
3	2		8	14B22
3	3		17	21WF55
COLUMNS				
3	1		10	14WF53
3	2		9	14WF40
3	3		12	14WF61
3	4		13	14WF74
BRACES				
3	3	1	1	1EAN1.6
3	3	2	1	1EAN1.6

****

TOTAL MATERIAL COST AND WEIGHT AFTER ELASTIC STRESS AND STIFFNESS DESIGN

****
*   *   *   *

MEMBER	WEIGHT (TONS)	COST (DOLLARS)
BEAMS	3.51	1405.20
COLUMNS	3.67	1468.80
BRACES	.10	38.99
TOTAL	7.28	2912.99

WEIGHT AND COST BY GRADE OF STEEL.

BEAMS, 36.0 KSI., 3.513 TONS, 1405.20 DOLLARS.
COLUMNS, 36.0 KSI., 3.672 TONS, 1468.80 DOLLARS.
BRACES, 36.0 KSI., .097 TONS, 38.99 DOLLARS.

OUTPUT OF DESIGN RESULTS FROM FINAL PLASTIC DESIGN CHECK AFTER ELASTIC DESIGN

OUTPUT OF MEMBER PROPERTY CONFIGURATION -- FINAL PLASTIC DESIGN CHECK IN ELASTIC DESIGN

STORY	BAY	BRACE TYPE	SECT. NO.(START)	SECT. NO.(END)	START FINAL CHECK	END FINAL CHECK
BEAMS						
1	1		9	9	16B26	16B26
1	2		6	6	12B16P5	12B16P5
1	3		15	15	18WF45	18WF45
COLUMNS						
1	1		8	8	14WF43	14WF43
1	2		6	6	10WF39	10WF39
1	3		9	9	14WF48	14WF48

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  1      4                    11              11          12WF58          12WF58
BRACES
BEAMS
  2      1                    13              13          16WF36          16WF36
  2      2                     8               8          14B22           14B22
  2      3                    17              17          21WF55          21WF55
COLUMNS
  2      1                     8               8          14WF43          14WF43
  2      2                     6               6          10WF39          10WF39
  2      3                     9               9          14WF48          14WF48
  2      4                    11              11          12WF58          12WF58
BRACES
  2      3        1            1               1          1EAN1,6         1EAN1,6
  2      3        2            1               1          1EAN1,6         1EAN1,6
BEAMS
  3      1                    13              13          16WF36          16WF36
  3      2                     8               8          14B22           14B22
  3      3                    17              17          21WF55          21WF55
COLUMNS
  3      1                    10              10          14WF53          14WF53
  3      2                     9               9          14WF48          14WF48
  3      3                    12              12          14WF61          14WF61
  3      4                    13              13          14WF78          14WF78
BRACES
  3      3        1            1               1          1EAN1,6         1EAN1,6
  3      3        2            1               1          1EAN1,6         1EAN1,6

**********************************************************************************************************

FINAL TOTAL MATERIAL COST AND WEIGHT.


*************************************************
*           *                *                  *
*  MEMBER   * WEIGHT (TONS)  * COST (DOLLARS)   *
*           *                *                  *
*************************************************
*           *                *                  *
*  BEAMS    *      3,51      *     1405,20      *
*           *                *                  *
*  COLUMNS  *      3,67      *     1468,80      *
*           *                *                  *
*  BRACES   *       ,10      *       38,99      *
*           *                *                  *
*************************************************
*           *                *                  *
*  TOTAL    *      7,28      *     2912,99      *
*           *                *                  *
*************************************************

WEIGHT AND COST BY GRADE OF STEEL.

BEAMS, 36,0 KSI.,   3,513 TONS,   1405,20 DOLLARS.
COLUMNS, 36,0 KSI.,   3,672 TONS,   1468,80 DOLLARS.
BRACES, 36,0 KSI.,    ,097 TONS,     38,99 DOLLARS.
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OUTPUT OF COLUMN EFFECTIVE LENGTH FACTORS FOR FINAL PLASTIC DESIGN CHECK AFTER ELASTIC DESIGN
(BEAM EFFECTIVE LENGTH FACTORS = 1.00)

STORY	COLUMN	K = WIND FROM LEFT	K = WIND FROM RIGHT
1	1	1.780000	1.780000
1	2	1.270000	1.270000
1	3	1.410000	1.410000
1	4	1.530000	1.530000
2	1	1.000000	1.000000
2	2	1.000000	1.000000
2	3	1.000000	1.000000
2	4	1.000000	1.000000
3	1	1.000000	1.000000
3	2	1.000000	1.000000
3	3	1.000000	1.000000
3	4	1.000000	1.000000

OUTPUT OF VALUES FOR AISC COLUMN INTERACTION EQUATIONS 2.42 AND 2.43 AFTER FINAL PLASTIC DESIGN CHECK AFTER ELASTIC DESIGN

STORY	COLUMN	EQ. 2.42-WIND LEFT	EQ. 2.42-WIND RIGHT	EQ. 2.43-WIND LEFT	EQ. 2.43-WIND RIGHT
1	1	.618346	.622703	.717294	.641004
1	2	.650238	.647742	.763494	.719938
1	3	.848337	.847184	.981966	.750681
1	4	.876417	.874336	.955128	.601657
2	1	.670069	.693148	.620539	.641004
2	2	.757327	.756293	.721324	.719938
2	3	.816458	.812062	.748512	.750681
2	4	.798799	.766937	.616088	.601657
3	1	.699734	.721257	.703699	.641004
3	2	.731771	.757703	.773740	.719938

3	3	.779166	.785929	.714459	.750681
3	4	.722668	.697773	.632675	.601657

OUTPUT OF VALUES FOR AISC BEAM INTERACTION EQUATION 2.43 AFTER FINAL PLASTIC DESIGN CHECK AFTER ELASTIC DESIGN

STORY	BEAM	EQ. 2.43-WIND LEFT	EQ. 2.43-WIND RIGHT
1	1	.804208	.795805
1	2	.606240	.618418
1	3	.757337	.766661
2	1	.816528	.782279
2	2	.635400	.588056
2	3	.745416	.746271
3	1	.793156	.774977
3	2	.594452	.581106
3	3	.754898	.762650

****
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* E N D   E L A S T I C   D E S I G N *

****
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FINISH

GOOD-BYE

APPENDIX III

ICES PLADS I DOCUMENTATION

Introduction

In order to provide the user with some necessary documentation of ICES PLADS I, this appendix is provided. Described herein will be the structure of the PLADS I load modules, providing information such as size in words of core, listing of members for each load module and the function performed by each load module, and a macro flowchart of the PLADS I load module structure. In conjunction with this topic, a method for determining an amount of core which will allow a given PLADS I job to execute efficiently will be presented. In addition, a listing of all the necessary job control statements to generate PLADS I from card source will be provided. At this time, this information is only available for U1100 series ICES.

Documentation of PLADS I Load Modules

The following documentation provides information regarding the PLADS I subsystem load modules such as load module name and structure, size in decimal words, and function, and a macro flowchart of PLADS I load module structure (Figure 23).

1. Load Module: PLDAR
   Element: PLDAR*
   Sizes: IBANK = 249, DBANK = 9
   Function: Initializes all global PLADS I dynamic arrays for input.

2. Load Module: PLDATA
   Elements: PLDATA*
   Sizes: IBANK = 201, DBANK = 10

3. Load Module: PLDAT1
   Elements: PLDAT1*
   Sizes: IBANK = 224, DBANK = 12

4. Load Module: PLDAT2
   Elements: PLDAT2*
   Sizes: IBANK = 70, DBANK = 10

5. Load Module: PLDAT3
   Elements: PLDAT3*
   Sizes: IBANK = 762, DBANK = 15
   Function: These four load modules(2 through 5) are used for the purpose of executing PLADS I problem data input.

6. Load Module: PLOUTP
   Elements: PLOUTP*
   Sizes: IBANK = 875, DBANK = 2073
   Function: Controls output of input data.

7. Load Module: PLASTC
   Elements: PLASTC*
   Sizes: IBANK = 3072, DBANK = 636
   Function: This load module functions as the executive for the plastic design part.

8. Load Module: PLSECT
   Elements: PLSECT*
   Sizes: IBANK = 684, DBANK = 122
   Function: Controls the input of the section property tables.

9. Load Module: PLMEM
   Elements: PLMEM*
   Sizes: IBANK = 980, DBANK = 42
   Function: Controls input of the individual member properties for elastic analysis and design.

10. Load Module: PLBMV
    Elements: PLBMV*, PLXLD*, PLIND*, PLLST, PLIN1*,

PLDES*, REDUCE*, IAISC, IWFNO, ISRCH, GAGBKX, KROUT

Sizes: IBANK = 5256, DBANK = 1058

Function: This load module performs an input check and computes the member property equations and equivalent beam and joint loads prior to the initiation of the plastic design cycles. And at the beginning of each plastic design cycle, this load module determines the force diagram for the factored gravity load condition and performs a design for this condition.

11. Load Module: PLSEN

Elements: PLSEN*, SEN1, SEN11, SEN2, SEN22, PMDH1*, PMDH2*, DFRC, DA21, DA22, FRM22, PMPR1, PMPR2, PLMN1*, PLINI*, PFOR1, PFOR2, PDELTA*, IAISC, ISRCH, IWFNO, GAGBKX, KROUT

Sizes: IBANK = 23407, DBANK = 1628

Function: This load module computes sensitivity coefficients, incremental shear to be applied to the panel with the minimum sensitivity coefficient, and after the distribution of each increment of story shear computes a new force distribution for which new member sizes are computed.

12. Load Module: PLOUT

Elements: PLOUT*

Sizes: IBANK = 302, DBANK = 149

Function: Outputs design data at the close of each plastic design cycle and at the end of the complete plastic design execution.

13. Load Module: PRBM1

Elements: PRBM1*, PRRMP1*

Sizes: IBANK = 381, DBANK = 474

Function: Output of analysis information at the close of each plastic design cycle and at the close of the complete plastic design cycle.

14. Load Module: COLSET

Elements: COLSET*, ISRCH

Sizes: IBANK = 929, DBANK = 88

Function: Satisfies the two tier column constraint.

15. Load Module: COST
Elements: COST*
Sizes: IBANK = 1075, DBANK = 282
Function: Computes and outputs cost data at the close of the complete plastic and elastic design stages.

16. Load Modules: STCWKB
Elements: STCWKB*, AISC, IAISC
Sizes: IBANK = 3597, DBANK = 225
Function: Satisfies the weak beam - strong column design constraint.

17. Load Module: ELASTIC
Elements: ELASTIC*, ELSTR, PLSTR
Sizes: IBANK = 4972, DBANK = 967
Function: Executive program for elastic stress and stiffness design.

18. Load Module: ELCHK
Elements: ELCHK*
Sizes: IBANK = 507, DBANK = 406
Function: Performs input data check for elastic stress and stiffness design.

19. Load Module: DEFCN
Elements: DEFCN*, DEFSN, DDMAX, COLSET, APRDS, APRDE
Sizes: IBANK = 6134, DBANK = 470
Function: Performs elastic stiffness design.

20. Load Module: FORCE
Elements: FORCE*, ICALK, AKMBR*, KSTUP, ICALK, SQRTM*, FSTUP*
Sizes: IBANK = 4995, DBANK = 312
Function: Computes elastic member forces.

21. Load Module: APRDS
Elements: APRDS*, APRDE*, APRDB*
Sizes: IBANK = 2750, DBANK = 247
Function: Computes approximate relative story deflections.

22. Load Module: PQSHR
Elements: PQSHR*
Sizes: IBANK = 278, DBANK = 42
Function: Computes beam rotation weighting factors used in the elastic stiffness design.

23. Load Module: ELOUT
Elements: ELOUT*

Sizes: IBANK = 275, DBANK = 138
Function: Outputs member sizes selected both before and after each execution of the elastic stress design or the final plastic design check.

24. Load Module: PLTIM
Elements: PLTIME*, CLOCK
Sizes: IBANK = 144, DBANK = 80
Function: Outputs process timing information.

25. Load Module: STIFF
Elements: STIFF*
Sizes: IBANK = 2006, DBANK = 303
Function: Executive program for elastic stiffness analysis.

26. Load Module: ELDES
Elements: ELDES*, PRSTR, ELSTR, ISRCH
Sizes: IBANK = 3021, DBANK = 221
Function: Performs the elastic stress design to satisfy the elastic stress constraints.

27. Load mosule: PRFOR
Elements: PRFOR*
Sizes: IBANK = 756, DBANK = 223
Function: Outputs elastic member end forces according the local sign convention.

*Denotes entry points

The following is a macro flowchart of the PLADS I load module structure, Figure 23.

The structure of PLADS I is such that, especially during plastic design, a certain number of these load modules, namely PLBMV and PLSEN, are referenced a large number of times throughout the plastic design process. Since the sizes of these load modules are substantially different, and due to the manner in which these two load modules share primary memory space, the author has found that core management was a critical factor governing the development and efficient operation of ICES PLADS I on U1100 systems.

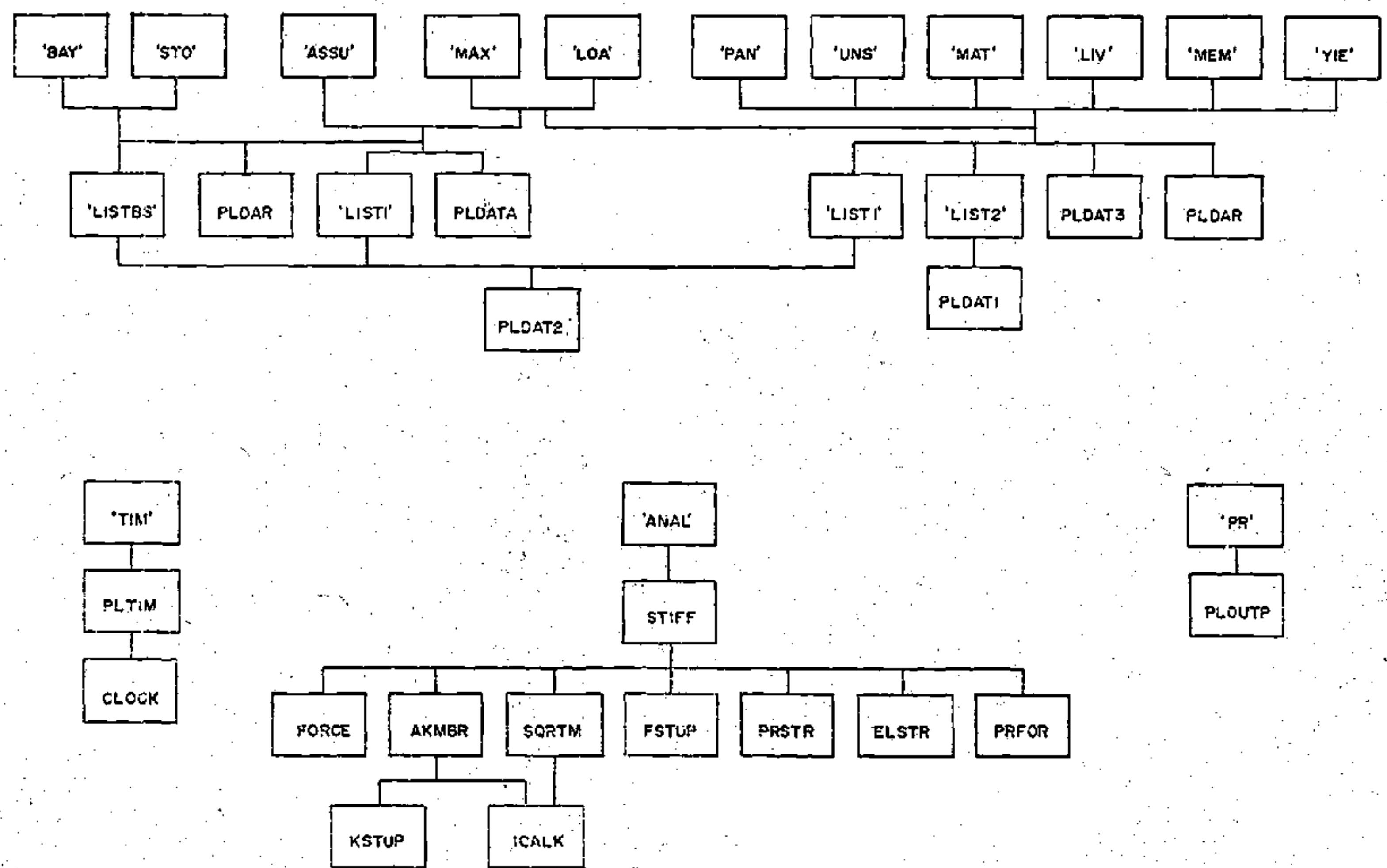

Figure 23. ICES PLADS I Macro Flowchart.

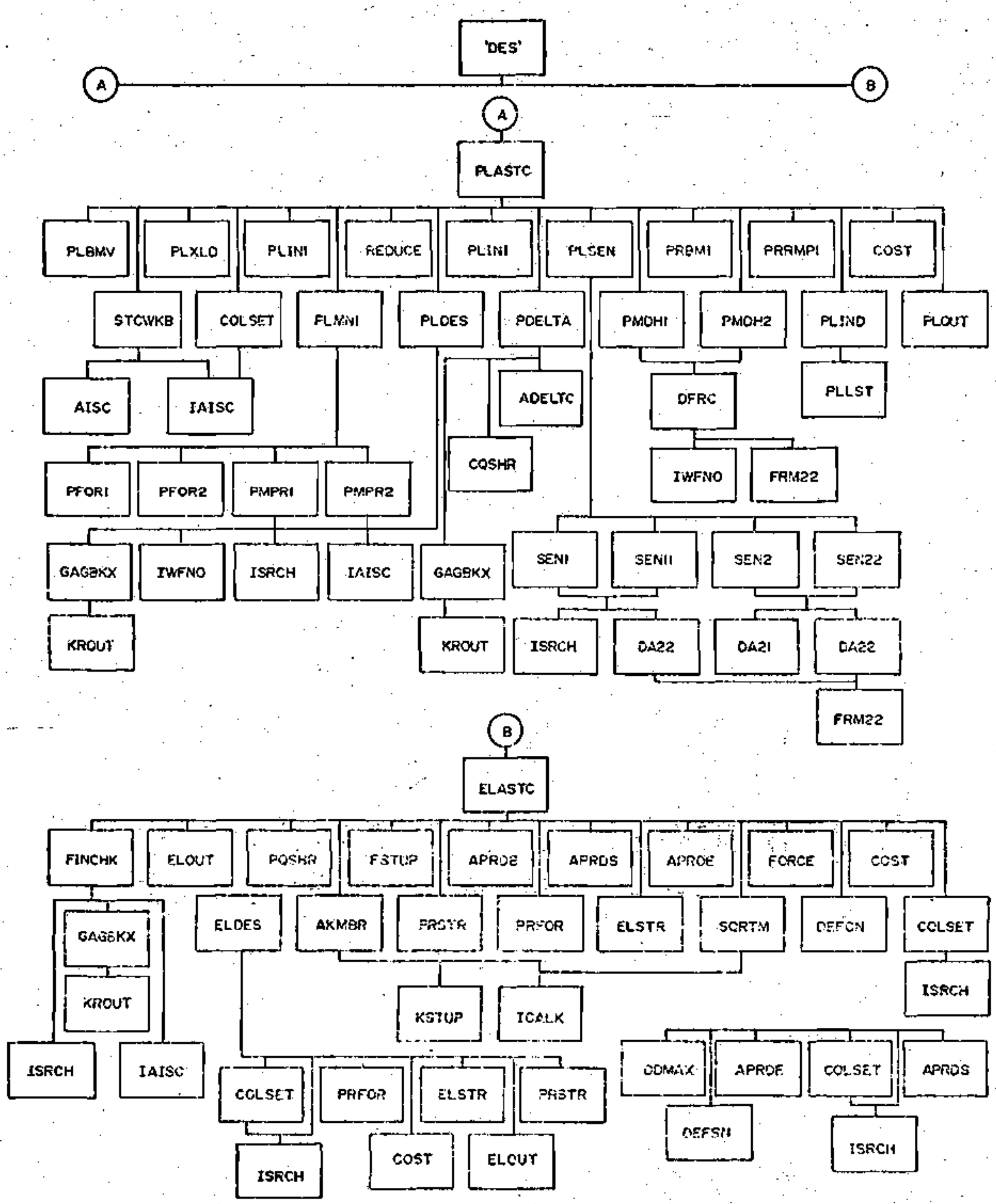

Figure 23. Continued

To give the user an idea of how much main core he will need to efficiently execute a job, the following formula for calculating necessary primary core in thousands of computer memory words is given:

CORE (in k words) = (70(NSTRY)(NBAY)+40(NSTRY)+ (A1)
35NBAY+50)/1000+(-1.35(NSTRY-3)+50Ln(NSTRY))

where,

NSTRY = number of stories

NBAY = number of bays.

This formula reflects the manner in which 54290 word core blocks are broken down for use by ICES. Following is a table which describes this breakdown:

Table 11. UNIVAC 1100 Series ICES primary Memory Management

AMOUNT OF CORE	USE AND COMMENTS
10 k words	Immovable fixed data area. Holds module common and DBANKs. Command Interpreter(CI) DBANK = 2 k words.
25 k	Movable area of core for use by user. Holds data pool for dynamic arrays, CI, and subsystem modules. CI uses about 1.5 k words for its IBANK.
20 k	ICES executive area. ICES executive IBANK and DBANK both use 10 k words.

The user's area of core described above may be increased in size by using the Z option when calling the ICES processor - @*SYSTEM.ICES,Z - or by specifying the amount of core needed on the same card - @*SYSTEM.ICES XXK. The latter method is, by far, more efficient and the amount of core needed to be specified is easily calculated using Formula A1.

The amount of core specified using Formula A1 will insure that the major parameter contributing to ICES PLADS I inefficiency, primary mory reorganization, is minimized.

ICES PLADS I Generation Job Control Language

This section lists the U1108 EXEC 8 job control language used by the author to generate ICES PLADS I from card source.

To maintain a current ICETRAN element source file PLADSELT on any U1108 mass storage device, the following job control stream was used.

```
@RUN  Individual accounting information
@QUAL  Anyqualifier -  set once and for all
@ASG,AX *PLADSELT.,F
@ELT,IN *PLADSELT.
        .
    ICETRAN Subroutine
        .
@ELT,IN *PLADSELT.subroutinename
        .
    ICETRAN Subroutine
        .
@FIN
```

To generate a current PLADS I relocatable binary element file PLADS of all PLADS I subroutines, the following job stream was used.

```
@RUN Individual accounting information
@QUAL qualifier
@ASG,AX *SYSTEM.,F
@ASG,AX *PLADSELT.,F
@ASG,AX *PLADS.,F
@*SYSTEM.ICE *PLADSELT.subroutinename1,*PLADS.
@*SYSTEM.ICE *PLADSELT.subroutinename2,*PLADS.
     .
     .
     .
@FIN
```

To generate a current PLADS I load module file PLADSMOD the following job stream was used.

```
@RUN Individual accounting information
@QUAL qualifier
@ASG,AX *FUNCLIB.,F
@ASG,AX *PLADS.,F
@ASG,AX *PLADSMØD.,F
@MAP,RL ,*PLADSMØD.loadmodulename
LIB *FUNCLIB,SYS$*RLIB$
REF NWDU$,NRDU$,NIØ1$,NIØ2$,NIØ3$,NERR3$,NERR2$
REF NERR$,NERRA$,NERRB$,NERRC$
IN *PLADS.subroutinename1,.subroutinename2,.,.,.
DEF entrypoint1,entrypoint2,...,
@FIN
```

Prior to the above generations, the user's UNIVAC 1100 computing system must have the files SYSTEM, containing all of the ICES basic system programs, and FUNCLIB, containing all of the necessary ICES functions, loaded on the system's mass storage unit.

The following JCL list describes the method used by the author to load the ICES CDB's (Command Definition Blocks) on the ICES system dictionary SYSDIC.

```
@RUN Individual accounting information
@QUAL qualifier
@ASG,AX *SYSTEM.,F
@ASG,AX *CDLMØD.,F
@ASG,AX *SYSDIC.,F
@USE SUB1.*CDLMØD
```

```
@*SYSTEM.ICESBIG
CDL
     .
     CDB's
     .
FINISH
@FIN
```

Where, again, the files SYSTEM, CDLMØD (containing the programs which make up the Command Interpreter) and SYSDIC (containing the Command Definition Language dictionary along with all other ICES subsystem CDL dictionaries) must be loaded prior to the execution of CDB generation.

The following JCL list describes the job control stream necessary to execute a PLADS I job.

```
@RUN Individual accounting information
@QUAL qualifier
@ASG,AX *SYSTEM.,F
@ASG,AX *CDLMØD.,F
@ASG,AX *SYSDIC.,F
@ASG,AX *PLADSMØD.,F
@ASG,AX *PLADSAV.,F
@USE SUB1,*CDLMØD
@USE SUB2,*PLADSMØD
@USE DD3,*SYSDIC
@USE DD4,*PLADSAV
@*SYSTEM.ICESBIG XXK
     .
     PLADS I INPUT data
     .
@FIN
```

Where PLADSAV is for the purpose of storing permanently saved PLADS jobs.

APPENDIX IV

PLADS I COMMAND DEFAULT VALUES

This appendix provides a table of PLADS I command default values for the commands which provide for them.

Table 12. PLADS I Command Default Values.

COMMAND	DEFAULT VALUE
1. MAXIMUM PERMISSIBLE ELASTIC STRESS AT WORKING LOADS	Specified yield stress for all members whose maximum elastic stress is not specified.
2. LOADING LATERAL/ CONCENTRATED/UNIFORM	0.0 for all stories/joints/ beams for which loading is not specified.
3. ASSUMED INITIAL RELATIVE DEFLECTION AT ULTIMATE LOADS	0.0005 x STORY HEIGHT for all stories whose initial relative story deflection is specified less than or equal to 0.01 inches.
4. UNSUPPORTED LATERAL LENGTH	48.0 inches for all beams and full story height for all columns whose unsupported lateral length is not specified.
5. MAXIMUM PERMISSIBLE MEMBER DEPTH	10000.0 inches for all beams and columns whose maximum depth is not specified.
6. OUTPUT	Final design and analysis information.
7. TOLERANCE FOR PDELTA CONVERGENCE	0.075
8. PDELTA COMPUTATION FOR COLUMN ELONGATION AND SHORTENING	NO

Table 12. Continued

COMMAND	DEFAULT VALUE
9. WEAK BEAM STRONG COLUMN CONSTRAINT	NO
10. LIVE LOAD REDUCTION FACTORS	0.00 for all columns whose live load reduction factor is not specified.

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